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Research Article

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Comparative studies of antioxidant activity and profile of some spices

Onyegbula, A.F.[1]; Ahmed, T., [1*]; Olorunfemi, A.P.[1], Lawal, I.O.[1] and Akande, E.J.[2]
Nigerian Stored Products Research Institute (NSPRI) Ilorin, Kwara State, Nigeria.
[1]Perishable Crops Research Department
[2]Durable Crops Research Department
**Corresponding author e-mail: ahmedt@nspri.gov.ng*
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ABSTRACT
Compounds that prevent or slow down the oxidation of lipids or other molecules like free radicals are known as antioxidants. The Study evaluated the antioxidant capacity, hydrogen peroxide scavenging capacity, and total flavonoid and phenol contents of six spices. Dried samples of spices were extracted in distilled water and analyzed using spectrophotometric and titrimetric methods. TAC results ranged from 232.79 - 64.32 mg/100g, with clove and black cardamom exhibiting the highest and lowest antioxidant activity respectively. The H_2O_2 scavenging activities result had clove and rosemary with the highest scavenging activity. Rosemary had the highest total phenol (5060 mg/100g) and flavonoid (1339 mg/100g) contents while black cardamom had the lowest values in both. Spices could be substituted for synthetic antioxidants in the food industry and as dietary sources of natural antioxidants.

Keywords: spices, antioxidant capacity, star anise, cinnamon, black cardamom, and fenugreek.

INTRODUCTION
In all cultures around the world, spices and herbs are traditionally utilized to enhance food flavor, they are also used medicinally to treat various ailments (Shirazi *et al*., 2014). Many plants used in traditional medicine contain high levels of polyphenols and flavonoids. These substances are an important source of phytochemicals for human and animal health in addition to aiding in the regulation of plant growth (Garg *et al*., 2019). Spices have long been utilized as aromatic and pungent food components that are used in a variety of dishes to enhance their flavor. Many plant components are used to make them, including cinnamon bark, clove flower buds, ginger roots, pimento fruits, white pepper berries, and other dried, edible, aromatic plants (Marti´nez-Tome *et al*., 2001; Przygodzka *et al*., 2014). The majority of these spices have a wide range of potential medical benefits, including their favorable effects on lipid metabolism, effectiveness as anti-diabetics, capacity to stimulate digestion, and potential as anti-inflammatory, and antioxidant qualities (Strabbiol and Murcia, 2001). Herbs and spices are rich in phytochemicals like polyphenols, phenolic acids, tannins, flavonols, isoflavones, and curcuminoids, which act as antioxidants and provide various health benefits. (Shirazi *et al*., 2014).

Atmospheric oxygen reacts with food containing fats or oil leading to the formation of peroxides and hydroperoxides, which eventually produce carbonyl compounds as secondary oxidation products (Embuscado, 2015). This chemical reaction happens when fats, oils, or meals containing lipids are subjected to oxidation. As a result, many foods develop smells and odors that can give them a rancid taste, thus rendering these items unfit for ingestion. Food products that are susceptible to this kind of chemical change currently require the usage of antioxidants to prevent food from spoiling due to oxidation (Choe and Min, 2009). Natural antioxidants that are derived from herbs and spices have varied levels of effectiveness when used in various culinary contexts. The human diet includes not just certain antioxidant vitamins like pro-vitamin A, vitamin E, and vitamin C but also a sophisticated blend of many naturally occurring chemicals that can act as antioxidants. Studies have also been conducted on aromatic plants as sources of various natural antioxidant classes. (Bowser *et al.*, 2014; Ozcan *et al*., 2009).

Antioxidants are substances that inhibit oxidative chain reactions, by preventing lipids and other molecules from oxidizing. As a result, antioxidants can avert damage caused to the body's cells by oxygen due to the redox potential of phenolic moieties (Choudhary *et al*., 2017; Suhartono *et al*., 2012). They exhibit their mechanism by acting as reducing agents, scavenging free radicals, quenching singlet oxygen and potentially complexing pro-oxidant metals (Bowser *et al.*, 2014; Suhartono *et al*., 2012). Flavonoids and other phenolic compounds are

secondary metabolites of plants that have an aromatic ring with a hydroxyl group or more (Ahmed *et al*. 2016). There are over 8,000 naturally occurring phenolic compounds found in plants, with half of them being flavonoids in various forms such as aglycones, glycosides, and methylated derivatives (Ahmed *et al*. 2016). One of the leading causes of food spoilage is lipid peroxidation, which can result in a loss of important nutrients and functional properties (Odukoya *et al*., 2005). The late 1940s saw the discovery that phenolic chemicals, or antioxidants, may reduce lipid peroxidation. This finding led to the development of chemical antioxidants such as tert-butylhydroquinone (TBHQ), Butylated hydroxyl anisole (BHA), butylated hydroxytoluene (BHT) and Propyl Gallate (PG) in the food processing industry, and have been dominant since their introduction. However, there are concerns by consumers about the use of synthetic food additives, hence the need for natural additives like herbs and spices, which are abundant in antioxidants (Saini *et al*., 2020; Choudhary *et al*., 2017; Odukoya *et al*., 2005).

This study aimed to investigate the total antioxidant capacity and hydrogen peroxide scavenging activity of different spices (bay leaf, clove, star anise, cinnamon, black cardamom, and rosemary) sold in Ilorin, Kwara State, Nigeria.

MATERIALS AND METHODS

Sample Collection

The spices (Bay leaf, Clove, Star anise, Cinnamon, Black Cardamom, and Rosemary) were purchased from Yoruba Road market, Ilorin, Kwara State, Nigeria.

Sample preparation

The methods of Maduike and Anuna (2018) with slight modifications were used for the preparation of the samples. A high-speed blender (model 8011ESK) was used to grind the spices into a fine powder, which was then stored in airtight containers till further use. To prepare the samples, 20 grams from each of the spices were weighed individually and then put in different containers. To every container, 100 millilitres of distilled water was added and heated to 60 °C for 1hr. afterwards, the solutions were filtered and the resulting liquid was collected in amber bottles and sealed for future use.

Determination of Total antioxidant Capacity (TAC)

The level of antioxidants present in a substance was measured using the phosphomolybdenum assay through spectrophotometry. To conduct the test, 1 mL of each extract was combined with a 3 mL solution that contained 28 mM sodium phosphate, 4 mM ammonium molybdate and 0.6 M H_2SO_4. The blank sample, which served as the control, only contained 4 mL of the reagent solution. The mixture of samples and reagent solution was then incubated at 95 °C for 150 minutes and subsequently cooled down to ambient temperature. A set of varying concentrations of ascorbic acid as standard was prepared and treated as test samples. The absorbance of both test samples and standards was read at 695 nm. TAC was expressed as an Ascorbic Acid equivalent Prieto *et al.,* (1999).

Hydrogen peroxide scavenging assay

To determine the percentage of scavenging of H_2O_2, the replacement titrimetric method described by Zhang (2000) was used. One (1) mL of each extract was mixed with 2 mL of 1 mM H_2O_2, 2 drops of 10 mL of 0.2 M sulphuric acid, 3% ammonium molybdate, 7 mL of 1.8 mM potassium iodide, and 2 drops of starch indication were added separately to each mixture. The resulting reaction mixture was titrated against 0.5 mM sodium thiosulphate until the blue colour disappeared. It was determined what percentage of H2O2 was scavenged using the following formula:

$$\boldsymbol{Inibition}\ (\%) = \frac{\boldsymbol{Vo - V1}}{\boldsymbol{V1}} \boldsymbol{X100}$$

Where V_o and V_1 are the volume of thiosulphate used for blank and samples respectively.

Determination of Total phenol content (TPC)

According to Tambe and Bhambar's (2014) description, the spectrophotometric approach was employed to ascertain the phenolic content of every extract. In a 25 mL volumetric flask, 1 mL of the extract and 9 mL of distilled water were combined to create each reaction mixture. Following that, 1 mL of Folin-Ciocalteu phenol reagent was added to the mixture and thoroughly shaken. Ten millilitres of a 7% sodium carbonate solution were added to the mixture after five minutes. Then, distilled water was added to get the volume up to 25 mL. Using the previously mentioned procedure, a standard solution set of gallic acid was prepared. After this, the solution was incubated for 90 minutes at ambient temperature, the absorbance of the solution was measured at 550 nm concerning the against reagent blank using an ultraviolet/visible spectrophotometer

Determination of Total Flavonoid content (TFC)

Tambe and Bhambar (2014) described the aluminium chloride colourimetric technique used to evaluate the extracts' total flavonoid concentration. One ml of extract and 4 ml of distilled water were put in a 10 ml volumetric flask and combined to create the reaction mixture. After adding 0.30 ml of 5% sodium nitrite to the flask and letting it stand for five minutes, the mixture was then mixed with 0.3 ml of 10% aluminium chloride, and it was left for an additional five minutes. Two millilitres of 1M sodium hydroxide were added to the solutions, and then distilled water was used to dilute it to ten millilitres. Using the same procedure, a collection of quercetin concentrations was prepared as a reference standard. Determination of the absorbance of the solutions

against the reagent blank at 510 nm was done using a UV/Visible spectrophotometer.

Statistical analysis

The experiments were conducted in triplicate to ensure accuracy and precision. The results were expressed as mean±SE (standard error) and analyzed using SPSS statistical software. The Duncan test was used to check the significance of the difference, and $P<0.05$ was considered significant.

RESULTS AND DISCUSSION

One of the primary mechanisms of phenolic phytochemicals' antioxidant effect is believed to be the scavenging of various forms of reactive oxygen species, primarily free radicals (Shan *et al*., 2005). The ability to provide hydrogen atoms and scavenge free radicals is reflected in anti-oxidation activity. Greater capacity is indicated by higher anti-oxidation action. (Odukoya *et al*., 2005). The result of TAC and H_2O_2 scavenging activity, as presented in Table 1 indicated a variation between the highest and lowest total antioxidant capacity. Clove exhibited the strongest total antioxidant capacity (437.12 mg/100g), which was significantly higher than rosemary (434.99 mg/100g). Shan *et al*. (2005) also reported high levels of total equivalent antioxidant capacity in Clove (168.7 mmol/100g of dry weight) where the total equivalent antioxidant capacity and total phenolic content of 26 spices were compared. Cinnamon and Bayleaf also had high total antioxidant capacity (232.79 and 210.30 mg/100g respectively) though with significant differences. Lu *et al*., (2011) also reported a strong total antioxidant activity for cinnamon. However Black cardamom recorded the lowest value (64.32 mg/100g) while Star anise had a value of 122.46 mg/100g.

According to Shan et al. (2005), clove has a high total antioxidant capacity due to its potent hydrogen-donating potential, metal-chelating capabilities, and efficacy as superoxide, hydrogen peroxide, and free radical scavengers According to Hossain *et al*. (2008), cinnamon's potent antioxidant action may be attributable to both its high eugenol content and its high cinnamaldehyde level. The spice extracts had remarkable H_2O_2 scavenging activity except Star anise and black cardamom whose inhibitory effects were below 50%. The hydrogen peroxide scavenging activity was highest in clove (96.73% inhibition) and lowest in star anise (48.59% inhibition).

Plant materials possess antioxidant properties because of the phenolic chemicals that are present in them (Soobrattee *et al.* 2005). Being among the most abundant and varied classes of natural chemicals, flavonoids are arguably the most significant natural phenolics. According to Panche *et al*., (2016), these substances possess a broad spectrum of chemical and biological actions, including the ability to scavenge radicals. According to Il-Suk *et al*. (2011), the antioxidant characteristics of flavonoids and phenolic compounds stem from their redox characteristics, capacity to chelate metals and singlet oxygen quenching ability. TPC and TFC levels in cloves were reported by Ali *et al*., (2021) to be 21510 mg GAE/100g and 560 mg quercetin equivalents (QE)/100g, respectively. Frohlich *et al*. (2022) extracted bioactive chemicals using an ultrasound-assisted extraction method and 70% aqueous ethanol at 60°C for 20 minutes as a solvent. They discovered a TPC of 38790 mg GAE/100g. Using boiling water (95°C) for three hours, Suantawee *et al*., (2015) extracted clove buds, yielding an extract with TPC and TFC values of 23960 mg GAE/100g extract and 6570 mg CE/100g extract, respectively. Ahmed et al. reported high levels of total flavonoid and phenolic content in their study in 2022. However, a new study has found lower levels of TPC and TFC, recording them to be 5036.11 mg/100g and 299.90 mg/100g respectively. The difference could be due to the variant of the species used in each study area and location. Two studies were conducted to determine the TPC and TFC of Rosemary. The first study by Megateli et al. (2018) found the TPC to be $12{,}787 \pm 2.1$ mg GAE/g dw and TFC to be 14.48 ± 1.5 mg QE/g dw using a plant material-to-liquid ratio of 1:2 (w/v). In contrast, the second study found significantly higher TPC and TFC levels, measuring at 5025.34 mg/100g and 1330.27 mg/100g, respectively. The TPC (2069.28 mg/100g) and TFC (330.82 mg/100g) levels of bay leaves in this investigation were likewise higher than those reported by Amal *et al.* (2018) (494.86±3.62 mg equivalent to gallic acid/g DM).

Table 1. Total Antioxidant Capacity and H_2O_2 Scavenging activity of selected Spices

Spices	Total Antioxidant capacity (mg/100g)	H_2O_2 scavenging activity (% inhibition)
Bay leaf	210.30c±0.08	88.95d±0.06
Clove	437.12f±0.03	96.73f±0.12
Star anise	122.46b±0.00	48.59b±0.16
Cinnamon	232.79d±0.05	85.76c±0.10
Black cardamom	64.32a±0.02	40.41a±0.05
Rosemary	434.99e±1.10	90.48e±0.14

The result shows the standard error of triplicate values. Means on the same column with unshared superscripts are significantly different (p<0.05)

Table 2: Total phenol content (mg/100g) of selected spices

Spices	Total Phenol (mg/100g)
Bay leaf	2069.28^{c}±0.14
Clove	5036.09^{e}±0.16
Star anise	1000.69^{b}±0.07
Cinnamon	3866.95^{d}±0.31
Black cardamom	410.37^{a}±0.42
Rosemary	5060.23^{f}±0.20

The result shows the standard error of triplicate values. Means on the same column with unshared superscripts are significantly different (p<0.05)

Table 3: Total flavonoid content (mg/100g) of selected spices

Spices	Flavonoids (mg/100g)
Bay leaf	330.83^{d}±0.02
Clove	299.91^{c}±0.14
Star anise	144.02^{b}±0.19
Cinnamon	709.89^{e}±0.19
Black cardamom	58.39^{a}±0.04
Rosemary	1339.51^{f}±0.08

The result shows the standard error of triplicate values. Means on the same column with unshared superscripts are significantly different (p<0.05)

Yang *et al*., (2012) discovered in their investigation on cinnamon that the total phenolic concentration (8.854 g/100 g DW) in 95% ethanol extract was twice as high as the Total flavonoid content (3.348 g/100 g DW). Cinnamon leaves from Ceylon were found to have a higher level of TPC (44.57 mg/g) and a lower content of TFC (12.00 mg/g) when extracted with 95% ethanol in a prior work by Wang et al. (2023). The TPC and TFC for cinnamon bark were 33.43 and 3.07 mg/g, respectively. However, these values were found to be much lower compared to the values obtained in the Yang *et al*., (2012) study, which reported TPC and TFC values of 3866.91 and 709.88 mg/100g respectively. Black cardamom (410.37 mg/100g, 8.39 mg/100g) and Star anise (1000.69 mg/100g, 144.02mg/100g) for TPC were the least recorded values for this study. As stated by Shan *et al*., (2005), the presence of phenolic compounds in plants and plant parts and their redox properties accounts for their antioxidant effect. This could be a justification for the scavenging strength of the spice extracts analyzed.

CONCLUSION

The study confirms that phenolic phytochemicals contribute to the antioxidant effect of spices by scavenging free radicals. Most of the substances present in natural extracts with demonstrated antioxidant action contain phenolic moiety. The majority of the spices in the study were shown to have significant levels of Phenol and flavonoid contents, H_2O_2 scavenging activity and total antioxidant capacity. These natural spices have a lot of potential to replace the artificial ones being processed and used in the food Industry.

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CONFLICT OF INTEREST

The author here by declare that there is no conflict of interest in the publication of this article.

REFERENCES

Ahmed, S. I., Hayat M. Q., Tahir, M., Mansoor, Q., Ismail M., Keck, K. and Bates R. B. 2016. Pharmacologically active flavonoids from the anticancer, antioxidant, and antimicrobial extracts of *Cassia angustifolia* Vahl. *BMC Complement Altern Med.* **16**, 460. doi: 10.1186/s12906-016-1443-z.

Bowser, T. J., Mwavita, M., Al-Sakini, A., McGlynn, W. and Maness, N. O. 2014. Quality and shelf life of fermented lamb meat sausage with rosemary extract. *Food Sci. Jour*. **8**, 22-31.

Choe, E. and Min, D. B. 2009. Mechanisms of Antioxidants in the Oxidation of Foods. *Compr. Rev. Food Sci. Food Saf.* **8** (4): 345-358. https://doi.org/10.1111/j.1541-337.2009.00085.x

Choudhary, S., Pereira, A., Basu, S. and Verma, A. K. 2017. Differential Antioxidant Composition and Potential of some Commonly Used Indian Spices, *J. Agri Search* **4**(3):160-166.

Embuscado, M. E. 2015. Spices and herbs: Natural sources of antioxidants – a mini-review. *J. Funct. Foods*, **18**, 811-819.

https://doi.org/10.1016/j.jff.2015.03.005

Garg, S. K., Shukla, A. and Choudhury, S. 2019. Polyphenols and Flavonoids. In: Gupta, R., Srivastava, A. and Lali, R. (ed). Nutraceuticals in Veterinary Medicine, Springer, Cham. 187-204. https://doi.org/10.1007/978-3-030-04624-8_13

Hossain, M., Brunton, N., Barry-Ryan, C., Martin-Diana, A. and Wilkinson, M. 2008. Antioxidant Activity of Spice Extracts and Phenolics in

Comparison to Synthetic Antioxidants. *Rasayan J.Chem.* **1**(4):751-756.

https://doi.org/10.1007/978-3-030-04624-8_13

Il-Suk, K., Mi-Ra, Y., Ok-Hwan, L. and Suk-Nam, K. 2011. Antioxidant Activities of Hot Water Extracts from Various Spices. *Int. J. Mol. Sci.* **12:** 4120-4131; doi: 10.3390/ijms12064120

Lu, M., Yuan, B., Zeng, M. and Chen, J. 2011. Antioxidant capacity and major phenolic compounds of spices commonly consumed in China. *Food. Res. Int.* **44**: 530-536.

Maduike, E. M. and Anuna, N. C. 2018. Infrared Spectroscopy and Microorganisms Associated with African Nutmeg (Monodora myristica) Seeds sold in a Municipal Market in Imo State, Nigeria. *Asian J.Res. Med. Pharm. Sci*., **3**(3): 1-7.

Odukoya, A. O., Ilori, O. O., Sofidiya, M. O., Aniunoh, O. A., Lawal, B. M. and Tade, I. O. 2005. Antioxidant activity of Nigerian dietary spices. *Elec. J. Env. Agricult. Food Chem.* **4** (6):1086-1093

Ovais Ullah Shirazi, Muhammad Muzaffar Ali Khan Khattak, Nor Azwani Mohd Shukri, Mohd Nur Nasyriq. A. (2014). Determination of total phenolic, flavonoid content, and free radical scavenging activities of common herbs and spices. *J Pharmacogn Phytochem*. **3** (3):104-108

Ozcan, M. M., Ozcan, E. and Herken, E. E. 2019. Short Communication: Antioxidant Activity, Phenolic Content, and Peroxide Value of Essential Oil and Extracts of Some Medicinal and Aromatic Plants Used as Condiments and Herbal Teas in Turkey. *J. Med.Food*. **12** (1): 198–202.

Panche, A. N., Diwan, A. D. and Chandra, S. R. 2016. Flavonoids: An overview. *J. Nutri. Sci.*, **5** e47. https://doi.org/10.1017/jns.2016.41

Prieto, P., Pinda M. and Aguilar, M. 1999. Spectrophotometric quantification of antioxidant capacity through the formation of a phosphomolybdic complex: Specific application to the determination of Vitamin E. *Anal. Biochem.*, **269**: 337-341

Przygodzka, M., Zieli_nska, D., Ciesarová, Z., Kukurová, K. and Zieli_nski. H. 2014. Comparison of methods for evaluation of the antioxidant capacity and phenolic compounds in common spices. LWT - *Food Sci. Tech.* **58**:321-326.

Saini, A., Pandey, A., Sharma, S., Ambedkar, Y. R., Suradkar, U. S. and Meena, P. 2019. Effect of rosemary (*Rosmarinus officinalis* L.) leaves extract on quality attributes of chicken powder incorporated fried chicken snacks, *J. Anim. Res.* **9** (4):565-571.

Saini, A., Pandey, A., Sharma, S., Suradkar, U. S., Ambedkar, Y. R., Meena, P., Raman, R. and Gurjar, A. S. 2020. Assessment of antioxidant activity of rosemary (*Rosmarinus officinalis*) leaf extract. *J. Pharmacogn. Phytochem*., **9** (3): 14-17.

Soobrattee, M. A., Neergheen V. S., Luximon-Ramma A., Aruoma O. I. and Bahorun, T. 2005. Phenolics as potential antioxidant therapeutic agents: Mechanism and actions. *Mutat. Res.-Fund. Mol. Mutagen.* **579**: 200–213. doi: 10.1016/j.mrfmmm.2005.03.023.

Shan, B., Cai, Y. Z., Sun, M. and Corke, H. 2005. Antioxidant capacity of 26 spice extracts and characterization of their phenolic constituents. *J. Agric. Food Chem.* **53**(20): 7749−7759.

Strabbioli, R. and Murcia, M. A. 2001. Antioxidant Properties of Mediterranean Spices Compared with Common Food Additives. *J. Food Pro*. **64**(9): 1412–1419.

Suhartonoa, E., Vianib, E., Rahmadhanb, M. A., Gultomb, I. S., Rakhmanb, M. F. and Indrawardhanac, D. 2012. Total flavonoid and Antioxidant Activity of Some Selected Medicinal Plants in South Kalimantan of Indonesia. *Int. Conf. Asia Agric. Anim. (ICAAA)*: 23-24.

Tambe, V. D., and Bhambar, R. S. 2014. Estimation of Total Phenol, Tannin, Alkaloid and Flavonoid in Hibiscus Tiliaceus Linn. Wood Extracts. Research and Reviews: *J Pharmacogn Phytochem*. **2**(4). 41–47.

Zhang, X. Y. 2000. Principles of Chemical Analysis. China Science Press, Beijing, China, 275-276.

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Research Article

In *Brassica rapa* meiotic recombination; chromosome axis remodeling is critical

Sana-e-Mustafa
School of Biosciences, University of Birmingham UK
**Corresponding author e-mail: Sanamustafa45@gmail.com*
(Received: 19/01/2024; Revised: 17/03/2024; Accepted: 29/04/2024; Published: 20/06/2024)

ABSTRACT
The primary mechanism by which breeders generate biodiversity is meiotic recombination, which permits genetic rearrangement at every generation. It facilitates the accumulation of advantageous alleles and eliminates harmful mutations. With the development of one to very rarely more than three crossovers that are not randomly distributed, this mechanism is highly regulated. To ensure correct parental chromosomal segregation and the creation of unique allelic combinations, meiotic recombination is essential. Finding the variables affecting the rate and distribution of meiotic crossings (COs) is crucial because this process is strictly regulated, especially for plant breeding initiatives. Nevertheless, few high-resolution recombination maps exist for most crops, including the *Brassica* genus, and little is known regarding sex differences and intraspecific variation. Here, using progenies of cross populations from the crossed F_1s population, we reveal fine-scale resolution recombination landscapes for two female and one male cross in *Brassica rapa*. Parents are from very different lines, which stands for higher quality and yield.
Keywords: *Brassica rapa*, crossover, meiosis, meiotic chromosome axis remodeling, meiotic recombination

INTRODUCTION

In sexually reproducing animals, meiosis is a specialised cell division that involves separate homologous chromosomal assortment and homologous recombination (HR) to reorganise the maternal and paternal genomes. DNA double-strand breaks (DSBs) catalysed by SPO11 are the first step in the production of HR (Neale *et al*., 2005; Pan *et al*., 2011).

Brassica species might have evolved with 4 or 5 rounds of polyploidisation, so all the *Brassicas* seem to descend from a paleohexaploid ancestor. The last polyploidisation event occurred less than 10.000 years ago, by the hybridisation of three diploid ancestors of *B. rapa* (AA, 2n=20), *B. nigra* (BB, 2n=16) and *B. oleracea* (CC, 2n=18) to produce three allotetraploid species [*B. juncea* (AABB, 2n=36), *B. napus* (AACC, 2n=38) and *B. carinata* (BBCC, 2n=34)]. *B. rapa* is known as turnip rape, field mustard, or bird's rape. Cultivated forms include turnip; napa cabbage, bomdong, bok choy, rapini and rapeseed oil. This oil has become the 3rd most important source of edible vegetable oils in the world. The ancestral *B. rapa* probably originated in the Hindu Kush area of Central Asia (4000-6000 years ago). *B. rapa* has different characteristics that allow for use as a good model for the study of meiosis in *Brassicas*: its genome is relatively small about 390Mb (compared to *B. oleracea* [~630Mb]), the plants start flowering around 6-8 weeks and with TILLING mutant lines available, it has self-incompatibility for pollination and the genetic diversity within strains.

Genetic variation generated through the process of meiotic homologous recombination (HR) underpins plant breeding and efforts to deliver the rapid improvements in crops that will be required to ensure Food Security into the foreseeable future. HR is initiated by the programmed formation of DNA double-strand breaks (DSBs) by the SPO11 complex. DSBs are processed by components of the HR pathway where they are repaired as crossovers (COs), which recombine the homologous parental chromosomes, or non-crossovers (NCOs), where only short stretches of DNA are exchanged. In plants, most DSBs (90%+) are repaired as NCOs (Mercier *et al*., 2015). This limits the genetic variation that is generated in each meiotic division. Moreover, the distribution of COs, notably in cereal crops, is localized to particular chromosomal regions.

The phenomenon of chiasmata (chiasmatypie) was first hypothesized by Weissman (1885) and observed by Janssens (1909 University of Leuven, Belgium). Chiasmata co-relation with COs was proposed by Wilson and Morgan (1920). Creighton and McClintock (1931, 1935) demonstrated it using discernible chromosome features (heterochromatic knobs) in maize. Darlington (1937) corroborated Janssens discovery.

Chiasmata are the physical manifestation of crossovers at Diakinesis and Metaphase I meiotic stages. The frequency and localization of chiasmata can be inferred by the bivalent configurations observed at the end of Metaphase I when the spindle creates the bipolar tension

needed to orientate the homologous chromosomes to opposite poles at Anaphase I. This tension united with the sister chromatid cohesion and the position of the chiasmata will produce different configurations (Sybenga, 1975). COs sites can be visualised as chiasmata at diakinesis (DK) and metaphase I (MI). Chiasmata seem to be localised preferentially in distal regions (close to telomeres) with very little in interstitial or proximal regions in *Arabidopsis*, *Brassica* and *Triticum* species. This is a serious constraint for plant breeders. In this work, we have analysed cytogenetically different aspects of *B. rapa* meiotic recombination to have a better insight into its control and how it could be manipulated.

MATERIALS AND METHODS

Cytology methods

Fluorescence in situ hybridization

With a few minor adjustments, cytological techniques were performed according to Armstrong *et al.* (2009) description. Using Texas Red and Atto488 (NT labelling kits, Jena Biosciences), 5S (pCT4.2; Campell *et al.*, 1992) and 45S (pTa71; Gerlach and Bedbrook, 1979) rDNA fluorescence in situ hybridization (FISH) probes were tagged by nick translation. Five anthers per slide were used for chromosomal spreading in *B. rapa* for immunostaining; the material was disrupted with a brass rod during the first four minutes of the eight-minute digesting process in a moist chamber at 37 °C; and 1.5% lipsol was used for the spreading process.

Table 1. DNA isolation and sequencing

Material	Information
B. rapa r-o-18	Laboratory control / Fully Sequenced
B. rapa 26155	Quality oily traits
B. rapa 26156	Yield
B. rapa 26155 x 26156	F_1 hybrid combining both yield and quality

RESULTS AND DISCUSSION

Pollen mother cells from *B. rapa* r-o-18 were used to analyse the different stages of meiosis and produce a meiotic atlas.

The localization of the chiasmata was inferred from the different shapes of the bivalents at metaphase I (Sybenga, 1975). Distal chiasmata (d) were located close to the telomeres, and interstitial chiasmata (i) were located more internally along the length of the chromosome arm (two different regions were classified as i1 closer to the telomere and i2 closer to the centromere). Proximal chiasmata were located near centromeres but at *B. rapa* were never observed.

Thus, this metaphase I contains 10 bivalents, 5 rings and 5 rods with a total of 15 chiasmata. The localisation can be classified as 11 distal (d), 3 interstitial 1 (i1) and 1 interstitial 2 (i2). This higher number of distal chiasmata (crossover/recombination) is very similar to that observed in other plant species (Mercier *et al.*, 2015). This distal crossover localization has serious consequences on the probability of introgression of genetic traits that might be located in interstitial and even proximal locations.

Fluorescence in situ hybridization using 45S and 5S rDNA probes was carried out to identify some chromosomes: A1 with 45S (green) and 5S (red) rDNA signals, A3 with also 45S and 5S signals but the 45S signal being smaller than in A1, A6 just with 45S rDNA signal and A10 just with 5S rDNA signal. Another bivalent with a 5S signal was observed that has not previously been identified (Waminal *et al*., 2016).

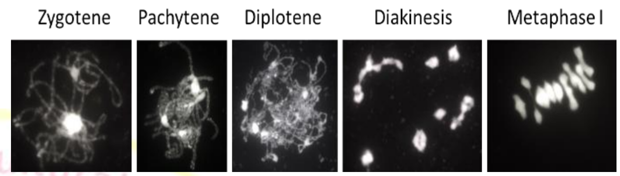


Fig 1. Different stages of meiosis at meiotic atlas

At metaphase we analysed the meiotic configurations observed, mainly ring and rod bivalents as in other species (Sybenga, 1975).

Fig 2. Meiotic configurations at the meiotic atlas

The localization of the chiasmata was inferred from the different shapes of the bivalents at metaphase I (Sybenga, 1975). Distal chiasmata (d) were located close to the telomeres, and interstitial chiasmata (i) were located more internally along the length of the chromosome arm (two different regions were classified as i1 closer to the telomere and i2 closer to the centromere). Proximal chiasmata were located near centromeres but at *B. rapa* were never observed.

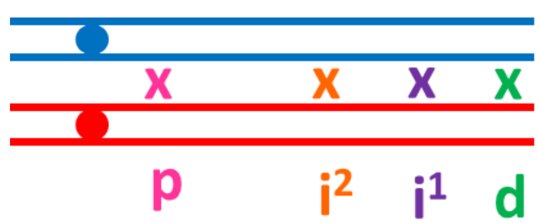


Fig 3. Chiasma frequency and localization analysis at meiotic atlas

This metaphase I cell is an example of the chiasma frequency and localization analysis done on *B. rapa*.

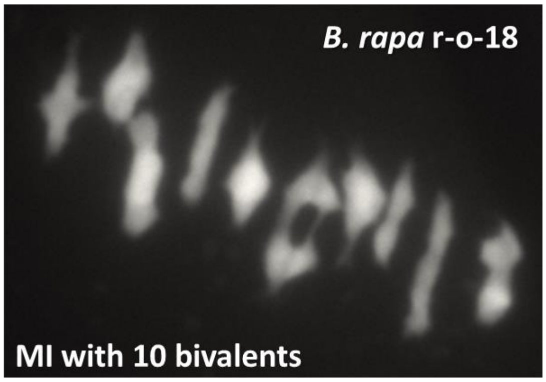
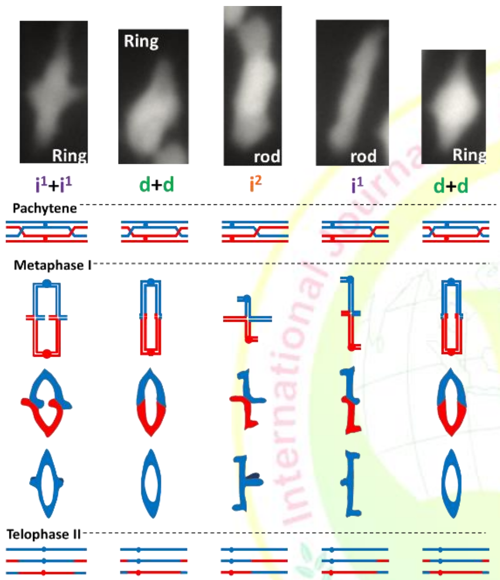


Fig 4. Chiasma frequency and localization analysis at meiotic atlas



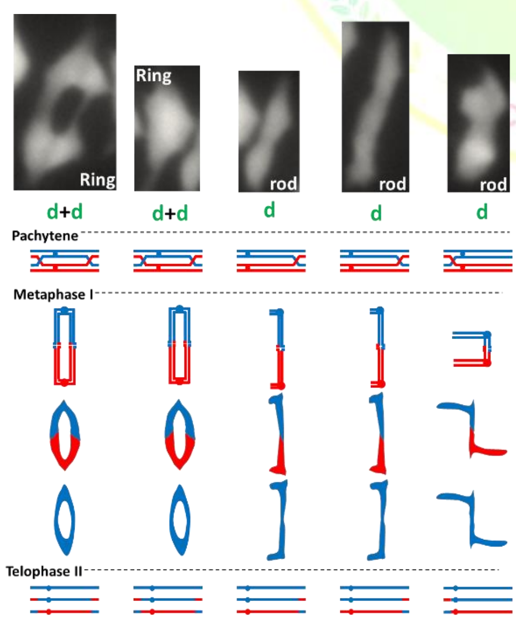


Fig 5. Chiasma frequency and localization analysis at meiotic atlas

Thus, this metaphase I contains 10 bivalents, 5 rings and 5 rods with a total of 15 chiasmata. The localisation can be classified as 11 distal (d), 3 interstial 1 (i1) and 1 interstitial 2 (i2). This higher number of distal chiasmata (crossover/recombination) is very similar to that observed in other plant species (Mercier *et al*., 2015). This distal crossover localization has serious consequences on the probability of introgression of genetic traits that might be located in interstitial and even proximal locations.

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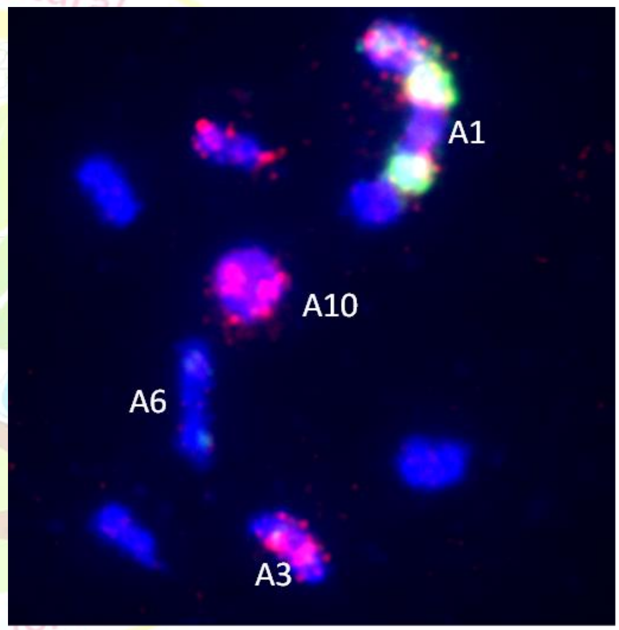
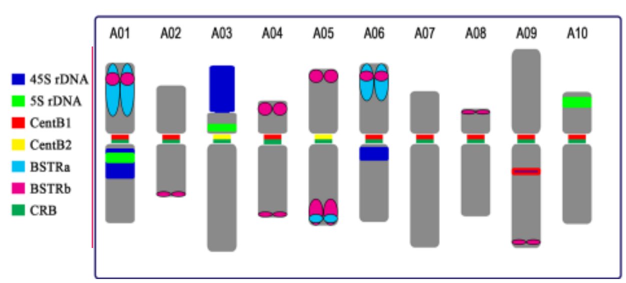


Fig 6. Fluorescence in situ hybridization using 45S and 5S rDNA probes to identify chromosomes



In *B. rapa*, recombination rates vary significantly across chromosomes; yet, Mb-scale landscapes are highly preserved across genetic backgrounds. In all *B. rapa* crosses, we found that the CO distribution was preferentially distributed towards distal regions. These findings are in line with those found in distant species like potato (Marand *et al*., 2017), tomato (Demirci *et al*., 2017; Rommel Fuentes *et al*., 2020), maize (Kianian *et al*., 2018), and barley (Dreissig *et al*., 2020), as well as those found in related species like *B. olereacea* (Pelé *et al*., 2017) and *B. napus* (Bayer *et al*., 2015; Boideau *et al*. 2022). Recombination frequency and distribution are also said to be influenced by a variety of epigenetic variables; CO incidence is associated with poor DNA methylation, low nucleosome density, and enrichment in particular histone marks. These characteristics of open chromatin were not examined in this study. Large pericentromeric regions of the chromosome, which typically exhibit a high level of DNA methylation and K3K9me2 histone marks, are home to heterochromatin and euchromatin, respectively, and are found in distal gene-rich regions (Boideau *et al*., 2022; Choulet *et al*., 2014; Li *et al*., 2019; Swagatika & Tomar, 2016). The preferred prevalence of these epigenetic characteristics is consistent with the U-shaped CO distribution that we observed in *B. oleracea*. We found that the CO number varied significantly among the cross combinations. The relationship between parent relatedness and CO number is not supported by our data. Indeed, a substrate with high homology may aid recombinational repair, therefore we would anticipate a greater number of COs when the two parents exhibit higher relatedness levels. This is not a typical pattern, though. It has been consistently shown that variations in CO rate exist depending on a plant's genetic background. Among our cross combinations, we did not find any significant differences in the Mb-scale CO landscapes, despite variations in CO quantities. We have demonstrated significant CO variation based on the direction and combination of the cross, which is extremely important for breeders.

CONCLUSIONS

In sexually reproducing animals, meiosis is a specialised cell division that involves separate homologous chromosomal assortment and homologous recombination (HR) to reorganise the maternal and paternal genomes. Since CO numbers are limited and skewed towards chromosome ends in many crop species, restricting recombination and access to naturally occurring genetic variety and producing linkage drag, modifying CO frequency and distribution is of particular importance for plant breeding. Since many crop species have low CO levels that are skewed towards chromosome ends, which limits recombination and access to naturally occurring genetic variety and creates linkage drag, changing CO frequency and distribution is of particular relevance for plant breeding.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Bayer, P.E., Ruperao, P., Mason, A.S., Stiller, J., Chan, C.K.K., Hayashi, S., Long, Y., Meng, J., Sutton, T., Visendi, P. and Varshney, R.K. 2015. High-resolution skim genotyping by sequencing reveals the distribution of crossovers and gene conversions in *Cicer arietinum* and *Brassica napus*. *Theoretical and Applied Genetics*, **128**, pp.1039-1047.

Boideau, F., Richard, G., Coriton, O., Huteau, V., Belser, C., Deniot, G., Eber, F., Falentin, C., Ferreira de Carvalho, J., Gilet, M. and Lodé-Taburel, M. 2022. Epigenomic and structural events preclude recombination in *Brassica napus*. *New Phytologist*, **234**(2): 545-559.

Campell, B.R., Song, Y., Posch, T.E., Cullis, C.A. and Town, C.D. 1992. Sequence and organization of 5S ribosomal RNA-encoding genes of *Arabidopsis thaliana*. *Gene*, *112*(2): 225-228.

Choulet, F., Alberti, A., Theil, S., Glover, N., Barbe, V., Daron, J., Pingault, L., Sourdille, P., Couloux, A., Paux, E. and Leroy, P. 2014. Structural and functional partitioning of bread wheat chromosome 3B. *Science*, **345**(6194): 1249721.

Creighton, H.B. and McClintock, B. 1931. A correlation of cytological and genetical crossing-over in Zea mays. Proceedings of the National Academy of Sciences, 17(8): 492-497.

Creighton, H.B. and McClintock, B. 1935. The correlation of cytological and genetical crossing-over in *Zea mays*. A corroboration. Proceedings of the National Academy of Sciences, **21**(3):148-150.

Darlington C. D., 1937. Recent Advances in Cytology, Ed. 2nd Blakiston's Son & Co. Philadelphia.

Demirci, S., van Dijk, A.D., Sanchez Perez, G., Aflitos, S.A., de Ridder, D. and Peters, S.A. 2017. Distribution, position and genomic characteristics of crossovers in tomato recombinant inbred lines derived from an interspecific cross between *Solanum lycopersicum* and *Solanum pimpinellifolium. The Plant Journal*, **89**(3): 554-564.

Dreissig, S., Maurer, A., Sharma, R., Milne, L., Flavell, A.J., Schmutzer, T. and Pillen, K. 2020. Natural variation in meiotic recombination rate shapes introgression patterns in intraspecific hybrids between wild and domesticated barley. New Phytologist, **228**(6):1852-1863.

Kianian, P.M., Wang, M., Simons, K., Ghavami, F., He, Y., Dukowic-Schulze, S., Sundararajan, A., Sun, Q., Pillardy, J., Mudge, J. and Chen, C. 2018. High-resolution crossover mapping reveals similarities and differences of male and female

recombination in maize. *Nature communications*, **9**(1): 2370.

Gerlach, W.L. and Bedbrook, J. 1979. Cloning and characterization of ribosomal RNA genes from wheat and barley. *Nucleic acids research*, **7**(7):1869-1885.

Janssens, F.A., Koszul, R. and Zickler, D. 2012. The chiasmatype theory. A new interpretation of the maturation divisions. 1909. *Genetics*, **191**(2): 319-346.

Marand, A.P., Jansky, S.H., Zhao, H., Leisner, C.P., Zhu, X., Zeng, Z., Crisovan, E., Newton, L., Hamernik, A.J., Veilleux, R.E. and Buell, C.R. 2017. Meiotic crossovers are associated with open chromatin and enriched with Stowaway transposons in potato. *Genome biology*, **18**:1-16.

Mercier, R., Mézard, C., Jenczewski, E., Macaisne, N. and Grelon, M. 2015. The molecular biology of meiosis in plants. *Annual review of plant biology*, **66**: 297-327.

Neale, M.J., Pan, J. and Keeney, S. 2005. Endonucleolytic processing of covalent protein-linked DNA double-strand breaks. *Nature*, **436**(7053):1053-1057.

Pan, J., Sasaki, M., Kniewel, R., Murakami, H., Blitzblau, H.G., Tischfield, S.E., Zhu, X., Neale, M.J., Jasin, M., Socci, N.D. and Hochwagen, A. 2011. A hierarchical combination of factors shapes the genome-wide topography of yeast meiotic recombination initiation. *Cell*, **144**(5): 719-731.

Rommel Fuentes, R., Hesselink, T., Nieuwenhuis, R., Bakker, L., Schijlen, E., van Dooijeweert, W., Diaz Trivino, S., de Haan, J.R., Sanchez Perez, G., Zhang, X. and Fransz, P. 2020. Meiotic recombination profiling of interspecific hybrid F_1 tomato pollen by linked read sequencing. *The Plant Journal*, **102**(3): 480-492.

Swagatika, S. and Tomar, R.S. 2016. Modulation of epigenetics by environmental toxic molecules. *Advances in Molecular Toxicology*, **10**: 361-389.

Sybenga J., 1975. Meiotic Configurations: A Source of Information for Estimating Genetic Parameters, Monographs on Theoretical and Applied Genetics, Ed Springer-Verlag Berlin Heidelberg.

Waminal N.E., Perumal S., Lee J., Kim H., Yang T-J. 2016. Repeat Evolution in *Brassica rapa* (AA), *B. oleracea* (CC), and *B. napus* (AACC) Genomes. *Plant Breed. Biotech*. **4**(2):107-122

Weismann A. 1885. The continuity of the germ-plasm as the foundation of a theory of heredity (Die Kontinuität des Keimplasmas: eine Theorie der Vererbung) : 161–248 Essays upon Heredity and Kindred Biological Problems. Clarendon Press, Oxford (in German)

Wilson E. B., Morgan T. H. 1920. Chiasmatype and crossing over. *Am. Nat.* **54**(632): 193–219.

Citation: Sana-e-Mustafa 2024. In *Brassica rapa* meiotic recombination; chromosome axis remodeling is critical. *International Journal of Agricultural and Applied Sciences*, 5(1): 6-10. https://doi.org/10.52804/ijaas2024.512

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Review Article

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Nutritional and Health Promoting Attribute of Kidney Beans (*Phaseolus vulgaris* L.): A Review

Fatima Shabir* and Sajjad Ahmad Khan
School of Agricultural Sciences, Glocal University Saharanpur UP 247231, India
**Corresponding author e-mail: fatimashabir1415@gmail.com*
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ABSTRACT

Red kidney bean (*Phaseolus vulgaris* L.) is nutritious and their consumption is associated with many health benefits that can fight against protein malnutrition. Starch, the most common carbohydrate reserve in plants, is present in legume seeds and has been associated with both cultural and nutritional advantages. Kidney bean seeds' main constituent is starch, which accounts for 25–45% of their dry matter. It also goes by the names Rajmash and common bean. Kidney bean starches are more soluble and have less swelling than cereal starches, which suggests that they have more functional qualities. Due to its properties and interactions with other ingredients, particularly water and lipids, which can greatly affect the final product's quality, starch is of interest to both the food industry and human nutrition as a macro-ingredient in many foods.
Keywords: Red kidney beans, protein, carbohydrates, vitamins, flavonoids

INTRODUCTION

Legumes are a good source of protein—two to three times that of cereal grains—as well as dietary fibre, vitamins, minerals, and starch. In many nations where protein energy malnutrition is a major problem, the different kinds of beans are a staple diet and an inexpensive source of protein. Recently, Kidney beans has been identified as a possible substitute for meat products and as a strong antioxidant. Its lower glycemic index makes it beneficial for those with diabetes, as well as for those with cardiovascular conditions, atherosclerosis, breast cancer, and increased satiation (Gutiérrez-Uribe, 2013). The scientific name for kidney beans is *Phaseolus vulgaris* L. These are popular legumes that are valued for their nutritious content and adaptability in the kitchen (Jones *et al*., 2019; Uusiku *et al*., 2013). They contribute to dietary diversity and general well-being by being an essential component of many different cuisines around the world. Because of their reddish-brown coloring and kidney-shaped form, kidney beans are also known as "common beans" or "red beans." From ancient times, kidney beans have been cultivated and consumed. Kidney beans came from Central and South America and were then traded through the Columbian Exchange to other regions of the world (Gepts *et al*., 2008). Kidney beans are a staple food for many different kinds of people because they are grown across North and South America, Africa, and Asia nowadays. With their remarkable nutritional profile, kidney beans are a great complement to a balanced diet. They provide a harmonious combination of vital micronutrients and macronutrients. The macronutrients consist of a little quantity of fat, proteins, and carbs. Minerals like iron, potassium, and magnesium are among the micronutrients included in kidney beans, along with vitamins like folate, thiamine, and vitamin K (Drewnowski, 2014; Tsai *et al*., 2017). There are a number of health advantages linked to kidney bean eating. Kidney beans' high dietary fiber content helps to maintain regular bowel movements and the growth of good gut flora, both of which are helpful to digestive health (Pereira *et al*. 2013; Tosh *et al*. 2013). In addition to its ability to help control weight and glucose levels, this high-fiber legume may also lower the chance of developing chronic illnesses like heart disease and some forms of cancer (Bazzano *et al*., 2013; Aune *et al*., 2017). Kidney bean processing techniques have an effect on the nutrients they contain. Cooking techniques like steaming or boiling can assist kidney beans maintain their nutrients (Mudryj *et al*., 2014).

Techniques including canning, freezing, and dehydration also help to retain some of the nutrients (Martínez *et al*., 2019). Furthermore, kidney beans can have their levels of anti-nutritional factors decreased and their nutrient availability increased by soaking and sprouting (Aguilera *et al*. 2016; Yadav *et al*. 2020). Kidney beans are versatile enough to be used in the creation of goods with additional value. Dried kidney beans are ground to create kidney bean flour, which is becoming more and more well-liked for its numerous uses in baked goods, snacks, and gluten-free items (Bai *et al*., 2018). In

response to consumer expectations for healthier options, convenience foods and snacks made from kidney beans are also being developed (Yang *et al*., 2021).

Furthermore, the functional qualities of kidney bean protein isolates and extracts are being investigated for possible application in food formulations (Wang *et al*., 2020). Kidney beans are important for maintaining good health and warding off many ailments. Because of their high fiber content and low glycemic index, kidney beans can assist diabetics control their blood sugar levels (Viguiliouk *et al*., 2014; Bazzano *et al*., 2013).

Nutritional aspects

The most significant food legume for human consumption worldwide is *Phaseolus*. Its seeds are a good source of protein and nitrogen, but they are mostly composed of carbohydrates. In addition, it has sulphur, copper, iron, zinc, manganese, magnesium, potassium, phosphorus, and calcium. This legume is full of bioactive substances that play metabolic roles in both humans and animals, including lectins, phytates, oligosaccharides, and phenolics. *Phaseolus* has a protective effect against cardiovascular diseases because of its biological activities, which include the capacity for antioxidants, the reduction of cholesterol, and the reduction of low-density lipoproteins. Because of its phenolics, lectins, and protease inhibitors' anti-mutagenic and anti-proliferative qualities, it has also demonstrated positive effects against cancer. Because of its resistant starch and α-amylase inhibitor content, it has also demonstrated effects on diabetes and obesity. An overview of the health benefits of beans as a nutraceutical food is provided here. (Bhatty, 2016).

Antioxidant profile

According to Lima *et al*. (2016), antioxidants are substances that shield animal, human, and other cell types from the damaging effects of free radicals. Plants naturally produce flavonoids and phenolic acids, which are natural sources of antioxidants. According to Dai and Mumper (2010), they are more effective antioxidant sources than vitamins C, E, and carotenoids. The capacity of phenolic and flavonoid compounds to modulate antioxidant defence by scavenging radical species is what gives rise to their antioxidant properties (Cotelle, 2017). The number of free hydroxyl groups in the molecular structure determines the reduction property of phenolic compounds (Ghasemzadeh and Ghasemzadeh, 2011), whereas the position of hydroxyl groups and other features in the chemical structure determine the antioxidant potential of flavonoids (Saxena *et al*., 2012).

Manganese, a trace mineral that is vital for many enzymes involved in energy production and antioxidant defences, can be found in kidney beans. Manganese, for instance, is necessary for the essential oxidative enzyme superoxide dismutase, which neutralizes free radicals created in the mitochondria, our cells' factories for producing energy in (Pilbeanu *et al*., 2017).

Amino acids profile

Excellent amino acid profile is exhibited by red kidney beans, which are primarily high in arginine, leucine, aspartic acid, glutamic acid, and lysine. When combined with cereals and other products that contain sulphur, beans offer the ideal amount of essential amino acids (Boye *et al*., 2010a). Aspartic and glutamic acids are primarily acidic substances found in both raw and processed beans. The FAO/WHO amino acid requirements for teenagers are met by both raw and processed red kidney beans, with the exception of cysteine, methionine, and tryptophan. According to Audu and Aremu (2011), 10.2g of glutamic acid, 9.5g of aspartic acid, 1.2g of cysteine, 1.7g of methionine, 3g of histidine, 4.4g of alanine, 5.2g of glycine, 3.4g of threonine, 3.3g of proline, 3,7g of isoleucine, 3.1g of tyrosine, 4.6g of phenylalanine, 4.1g valine, 3.1g of serine, 6.9g of arginine, 7glysine, and 7.2g of leucine are supplied by red kidney beans per 100g. Legumes high in methionine and threonine are cowpeas. It also contains two non-essential amino acids, glutamic acid and aspartic acid. According to Iqbal *et al*. (2006), lentils are high in non-essential amino acids but cowpeas have a higher concentration of essential amino acids. The limiting amino acids for broad beans are cysteine and methionine. Though they are less common than eggs, most other EAAs nevertheless meet people's needs (Mortuza *et al*., 2009).

Dietary fiber

According to Zhang *et al*. (2011), dietary fibre can be categorized as soluble or insoluble, and each class has unique physiological effects (Ajila and Rao, 2013). For nutritional and functional qualities, the proportion of two classes of dietary fibre matters (Liu *et al*., 2021). The GIT is the site of bacterial fermentation that soluble dietary fibre encounters, impacting the metabolism of fats and carbohydrates. On the other hand, insoluble fraction prevents the growth of rectal cancer and lowers the incidence of constipation by shortening the gastrointestinal transit time (Bingham *et al*., 2018). Dietetic fibre is a diverse range of non-digestible substances, including resistant starch, soluble and insoluble fibre, and oligosaccharides like mullein, raffinose, and estachyose. According to Cruz-Bravo *et al*. (2011), the common bean (*Phaseolus vulgaris* L.), which is primarily consumed in Latin America, has a high fibre content. Rats fed a pancreatin-resistant fraction made from Phaseolus vulgaris beans (Kintoki beans) exhibited significantly higher levels of Cholesterol 7-α-hydroxylase when compared to rats fed a cellulose diet. In the small intestine, it also reduced bile acid absorption and raised intestinal content viscosity (Han *et al*., 2004). Long-term bean consumption has been demonstrated to lower serum levels of low-density lipoprotein (LDL) and cholesterol in humans, suggesting that beans may provide some protection against cardiovascular diseases (Bazzano *et al*., 2013). Phaseolus mungo fibre was isolated, and it revealed a neutral detergent residue (NDR). It significantly reduces

cholesterol and increases the excretion of bile acid in faeces (Rebello *et al*., 2014).

Gluten-free

A gluten-free diet is recommended for those with celiac disease, as gluten is a protein present in many grain products. Their diet has to change to exclude these products, which raises the possibility of deficiencies in various B-vitamins and other nutrients that are normally present in grains (Niewinski *et al*., 2008). In addition to having many of the same vitamins and minerals—such as thiamin, riboflavin, folate, iron, and fiber—that are frequently found in enriched grain products, beans are naturally gluten-free. Because bean flour can be combined with other gluten-free flour (like rice or tapioca flour) they may be especially helpful for people on gluten-free diets (Bai *et al*., 2018).

Health benefits of kidney beans

Kidney beans and cancer

One term for cancer is a multi-step disease. Cancer develops as a result of a variety of direct and indirect factors, including genetic, physical, chemical, metabolic, and environmental factors (Aparicio-Fernández *et al*., 2017). Cancer is thought to be caused by aberrant cells that divide cellularly and replicate their DNA on their own. This results in the formation of cancerous tumours, which destroy surrounding tissue and the lymphatic system. Red kidney beans are said to contain phenolic acids with anticancer properties (Nyau, 2014; Gibson *et al*., 2017). They have the ability to function as an inhibitor and prevent tumours from growing once they have started. According to Scalbert *et al*. (2015), they can also inhibit cell proliferation in vitro. More proof of a negative correlation between bean consumption and the development of cancer has come from epidemiological and preclinical research assessing prostate and colon cancer (Thompson *et al*., 2012). In developed nations, colorectal cancer ranks as the second most common cause of cancer-related deaths. Studies aimed at detecting it have not reduced the disease's incidence or mortality, so efforts to prevent it have centered on lifestyle modifications (Derry, Raina, Agarwal, & Agarwal, 2013). Dietary fibre may be protective against colorectal cancer, according to epidemiological data. According to a study (Reynoso-Camacho *et al*., 2007), rats given pinto, black, and white beans while they were being treated for colon cancer had four times fewer tumours grow.

Kidney beans and diabetes mellitus

The major goal of managing diabetes is controlling blood glucose levels. A key component of type 2 diabetes management is glycaemic control. By slowing down and reducing the absorption of glucose from the intestine, the soluble fibre fraction can regulate the glycemic (Ricardo-da-Silva *et al*., 2019)). Studies pertaining to individuals with diabetes have demonstrated that diets with lower GI ratings and higher fibre content result in better levels of glycated proteins, which can help regulate the glycaemic index (Kendall *et al*., 2016). According to Eshak *et al*. (2010), they can decrease the incidence of type 2 diabetes by decreasing the rate at which macronutrients are absorbed and digested, as well as the duration of time that the intestinal lumen is in contact with carcinogens (Raninen *et al*., 2011). Water soluble fibres enter the small intestine, thickening its contents and modifying the process of digestion by decreasing the time that nutrients diffuse for absorption and the interaction between food and digestive enzymes. A higher frequency of atherosclerotic plaques, endothelial dysfunction, and an increase in intima-media thickness are all correlated with hyperglycemia in type 2 diabetes mellitus (DM2). This is connected to a rise in oxidative stress brought on by thrombin synthesis, low-density lipoprotein oxidation, and platelet activation, all of which raise the risk of DM2-related cardiovascular illnesses (Barrett and Udani, 2011). The reduction of tiobarbituric acid and hydroperoxide reactive substances was observed in streptozotocin-induced diabetic rats after an oral administration of an ethanolic extract from *Phaseolus vulgaris* (200 mg/kg body weight) for 45 days. In the liver and kidneys, the extract significantly increased reduced glutathione, superoxide dismutase, catalase, glutathione peroxidase, and glutathione-S-transferase. According to Venkateswaran and Pari (2012), the extract was superior to glibenclamide in its ability to lower blood glucose levels.

According to Feregrino-Pérez *et al*. (2008), the starch in beans is slowly absorbed and reduces the postprandial response to insulin. In order to combat obesity and diabetes in humans, the α-amylase inhibitor isoform 1 (α-AI1) has been extracted and utilised in a variety of commercial products (Barrett and Udani, 2011, Zhang, and Jiang, 2008). Eating beans has been associated in epidemiological studies with a lower risk of obesity and overweight. Bean eaters in the US had a 23% lower chance of obesity and a lower systolic blood pressure in adults. According to research conducted on adult Brazilians, eating beans on a regular basis lowers the risk of obesity and overweight in both men (−13%) and women (−14%), (Nilsson, Johansson, Ekström, and Björck, 2013). Furthermore, studies have shown that a bean extract taken by people reduces body weight, fat percentage, and hip and waist circumference (Preuss, 2019).

Kidney beans and cardiovascular disease

Reducing the risk of stroke and cardiovascular disease as well as maintaining healthy blood pressure levels benefits heart health. Diets rich in fruits, vegetables, legumes, whole grains, fish, poultry, seeds, unsalted nuts, and low-fat or fat-free dairy products all lower blood pressure than the control diet, which was based on the average American diet, according to the D.A.S.H. (Dietary Approaches to Stop Hypertension) study. Aune *et al*., 2017 Potassium is naturally found in many of the food groups that make up the D.A.S.H. eating plan, including beans.

According to Marinangeli *et al*., 2017, people who ate legumes at least four times a week had a 22% lower risk of heart disease compared to people who ate them less

frequently. Consistent lower risks of heart disease have also been noted in epidemiological studies where the consumption of legumes as part of a healthier diet plan has been observed. Within the Health Specialists Men who followed a more "prudent" diet consisting of more whole grains, legumes, fish, and poultry had a 30% lower risk of heart disease, according to the Follow-up Study. On the other hand, people who ate a more "Western" diet—one that included more red meat, refined grains, sweets, French fries, and high-fat desserts—were at risk of developing heart disease (Hu, (2015). Corresponding patterns were observed in the Nurses' Health Study. The risk of heart disease was halved for those who regularly followed the "prudent" diet as opposed to those who mostly followed the "Western" diet. (Fung, 2011) Legumes have been shown in epidemiologic studies to have heart-protective properties when included in a balanced diet. One study in particular looked at the connection between the incidence of cardiovascular disease (CVD) and bean consumption; it found that consuming one serving (1/2 cup) of beans daily was linked to a 38% lower risk of myocardial infarction (Kabagambe, 2005). According to a second study, people who ate legumes at least four times a week had a 22% lower risk of heart disease compared to people who ate them less frequently (Marinangeli *et al*., 2017).

Kidney beans and degenerative diseases

Plant metabolites called polyphenols have strong antioxidant qualities that help lessen the effects of oxidative stress-related diseases. The data showed that because dietary polyphenols may help prevent degenerative diseases in people, there is a growing body of research investigating their potential benefits. The potential health benefits of polyphenols are contingent upon their consumption by humans and their bioavailability. *Phaseolus vulgaris* L., or common beans, are a better source of polyphenolic compounds, which have a variety of health-promoting qualities. The health benefits of dry common beans rich in polyphenols include their anti-oxidant, anti-diabetic, anti-obesity, anti-inflammatory, anti-mutagenic, and anti-carcinogenic qualities. In light of the research, the current thorough review seeks to offer current knowledge on the nutritional profiles and health-promoting properties of common beans high in polyphenols. This will aid in the exploration of these beans' potential therapeutic uses in light of future clinical investigations (Abd El-Hack *et al*., 2021).

Kidney beans and heart health

The majority of beans, including kidney beans, are excellent sources of fibre that lowers cholesterol. Kidney beans are a particularly good option for people with diabetes, insulin resistance, or hypoglycemia because of their high fibre content, which also lowers cholesterol and prevents blood sugar levels from rising too quickly after meals. Kidney beans are an almost fat-free source of high-quality protein when they are combined with whole grains like rice. However, kidney beans are far more beneficial than this. As a necessary component of the enzyme sulfite oxidase, which is in charge of detoxifying sulfites, kidney beans are a great source of the trace mineral molybdenum. A common type of preservative added to prepared foods like salad bars and delicatessen salads is sulfites. If sulfites are inadvertently ingested by someone who is sensitive to them, they may experience a fast heartbeat, headaches, or disorientation. You may not have enough molybdenum in your stores to properly detoxify sulfites if you have ever reacted to them (Abd El-Hack *et al*., 2021).

The consumption of foods high in calories density is increased by modern lifestyles, which leads to changes in eating habits. Diets high in fat and high glycemic index, primarily derived from processed and simple sugar-derived goods, raise the risk of developing chronic illnesses. The past few years have seen a decline in the consumption of pulses, especially beans. Research demonstrates that the significance of this vegetable food group lies not only in its nutritional value but also in its association with a decreased risk of serious chronic non-transmissible diseases. *Phaseolus* has a number of advantageous biological activities for humans, including effects on obesity, diabetes, and cardiovascular disease as well as lowering cholesterol and low-density lipoprotein and having anti-mutagenic and anticancer properties. It's critical to work towards increasing bean consumption in order to reap the benefits. Conversely, beans may provide a good source of nutraceuticals for human supplementation; these are primarily compounds that lose their biological activity when cooked (Ros *et al*., 2019)

CONCLUSIONS

Red kidney beans can help treat a wide range of chronic illnesses that affect people all over the world. Red kidney beans have a very promising future as functional foods and nutraceuticals. Increased use of improved varieties and scientific farm management techniques can result in a significant increase in red kidney bean yields.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Abd El-Hack, Hussein EO, Hafez HM, Noreldin AE, Saadeldin IM, Alagawany M. 2021. Potential use of plantderived natural products as alternative natural preservatives for meat and meat products: A comprehensive review. *Food Control*.; **122**:107762.

Aguilera Y, Esteban RM, Benítez V, Martín-Cabrejas MA, Molla E. 2016. Antinutritional factors and nutrient bioavailability of differently processed kidney bean (*Phaseolus vulgaris* L.) cultivars. *Food Chemistry*.; **197**:1300-1306.

Ajila, C.M. and Rao, U.J.S.P. 2013. Mango peel dietary fiber: Composition and associated bound Phenolics. J. *Funct. Foods* **5**, 444-450.

Aparicio-Fernández X, Llorente-Berzal A, Arráez-Román D, Castillo-Domínguez MC, Gómez-Serranillos MP, García-Granados A. 2017. The bioactivity of phenolic compounds against different chronic diseases: A review. *Molecules*. **22**(2):1-24.

Audu, S.S. and Aremu, M.O. 2011. Effect of Processing on Chemical Composition of Red Kidney Bean (*Phaseolus vulgaris* L.) *Flour. Pak. J. Nutr.* **10**,1069-1075.

Aune D, Keum N, Giovannucci E, Fadnes LT, Boffetta P, Greenwood DC, et al. 2017. Whole grain consumption and risk of cardiovascular disease, cancer, and all-cause and cause-specific mortality: systematic review and dose-response meta-analysis of prospective studies. *BMJ*. **357**:1907.

Bai Y, Sun Y, Luo Y, Zhang X, Ren H, Zhang M. 2018. Characterization of kidney bean flour and its application in gluten-free biscuit. *Journal of Food Science and Technology*. **55**(8):3233-3241.

Bazzano LA, Thompson AM, Tees MT, Nguyen CH, Winham DM. 2013. Non-soy legume consumption lowers cholesterol levels: A meta-analysis of randomized controlled trials. Nutrition, Metabolism, and cardiovascular diseases. **23**(4):356-363.

Bhatty RS. 2016. Composition and nutritional quality of kidney beans (*Phaseolus vulgaris* L.). In Advances in Food and Nutrition Research. Academic Press. **79**:67-118.

Boye, J.I., Zare, F. and Pletch, A. 2010a. Pulse proteins: processing, characterization, functional properties and applications in food and feed. *Food Res. Int.* **43**, 414- 431.

Dai, J. and Mumper, R. 2010. Plant phenolics: extraction, analysis and their antioxidant and anticancer properties. *Mole* 15, 7313-7352.

Derry, M.M., Raina, K., Agarwal, C., and Agarwal, R. 2013. Identifying molecular targets of lifestyle modifications in colon cancer prevention. *Frontiers in Oncology* **3**, 119.

Drewnowski A. 2014. Dietary patterns, food quality and human health: A review. *The FASEB Journal*. **29**(12):4077-4085.

Eshak, E.S., Iso, H., Date, C., Kikuchi, S., Watanabe, Y., Wada, Y., Kenji, W. and Akiko, T. 2010. Dietary fiber intake is associated with reduced risk of mortality from cardiovascular disease among Japanese men and women. *J. Nutr.* **140**, 1445-1453.

Fung, B.J., Yuan, S.H., and Chang, S.K.C. 2011. Comparative studies on the antioxidant activities of nine common food legumes against copper-induced human low-density lipoprotein oxidation in vitro. *Journal of Food Science* **72**(7), S522–S527.

Ghasemzadeh, A. and Ghasemzadeh, N. 2011. Flavonoids and phenolic acids: Role and biochemical activity in plants and human. *J. Med. Plants Res*. **5**, 6697-6703.

Gibson GR, Hutkins R, Sanders ME, Prescott SL, Reimer RA, Salminen SJ, et al. 2017. Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. *Nature Reviews Gastroenterology & Hematology*. **14**(8):491-502.

Guajardo-Flores, Daniel, Serna-Saldívar, Sergio O., and Gutiérrez-Uribe, Janet A. 2013. Evaluation of the antioxidant and antiproliferative activities of extracted saponins and flavonols from germinated black beans (*Phaseolus vulgaris* L.). *Food Chemistry* **141**(2), 1497–1503.

Hu and Fung. 2015. Rapid tests to assess the antioxidant activity of *Phaseolus vulgaris* L. dry beans. *Journal of Agricultural and Food Chemistry* **53**, 3053–3056.

Iqbal, A., Iqtidar, A., Khalil, N., Ateeq and Khan, M. S. 2006. Nutritional quality of important food legumes. *Food Chem.* **97**, 331-335.

Jones AD, Shrinivas A, Bezner-Kerr R. 2019. Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy*. **82**:50-58.

Kendall, E.K., Baylin, A., Ruiz-Narvarez, E., Siles, X., and Campos, H. 2016. Decreased consumption of dried mature beans is positively associated with urbanization and nonfatal acute myocardial infarction. *J Nutr*. **135**(7), 1770-1775.

Lima LR, Gonçalves RV, Barros HR, Negrão L. 2016. Chemical composition, antioxidant activity, and total phenolic content in different morphological parts of *Phaseolus vulgaris* L. seeds. *Journal of Food Science and Technology.* **53**(3):1471-1480.

Liu J, Liu F, He J, Zhao D, Zhang M, Sun X, et al. 2021. Effect of kidney bean protein isolate on dough properties and bread quality. *Food Science & Nutrition*. **9**(5):2676- 2683.

Marinangeli CP, Jones PJ, Ma DW 2017. Tannins in beans and other legumes: friends or foes?. *Food Research International*. **100**(Pt 2):476-484.

Martinez, T., Naczk, M., and Shahidi, F. 2019. Antioxidant activity of common beans (*Phaseolus vulgaris* L.). *Journal of Food Lipids* **11**, 220–233.

Mortuza, M.G. and Tzen, J.T. 2009. Physicochemical and functional properties of tencultivars of seem (*Lablab purpureus*L.), an underexploited bean in Bangladesh. *J. Sci. Food Agric*. **89**, 1277-1283.

Mudryj AN, Yu N, Aukema HM. 2014. Nutritional and health benefits of pulses. *Applied Physiology, Nutrition, and Metabolism.* **39**(11):1197-1204.

Niewinski, M.M. 2008. Advances in celiac disease and gluten-free diet. *J Am Diet Assoc.* **108**, 661-672.

Nilsson, Johnsson, Ekstrom and Bjorck, M. 2013. Grain legume proteins and nutraceutical properties. *Fitoterapia*, **77**: 67-82.

Nyau, V. 2014. Nutraceutical perspective and utilization of common beans (*Phaseolus vulgaris L*): A review. *Afr. J. Food Agri. Nutr. Deve.* **14**, 9483-9493.

Pilbeanu MA, Bele C, Muste S, Paun N, Stancu MM. 2017. Nutritional value and potential health benefits of legumes: A review. *Chemistry Central Journal*. **11**(1):1-18.

Preuss K, et al. 2019. Dietary fiber and risk of coronary heart disease: A pooled analysis of cohort studies. *Archives of Internal Medicine*. **164**(4):370-376.

Raninen, K., Lappi, J., Mykkanen, H. and Poutanen, K. 2011. Dietary fiber type reflects physiological functionality: comparison of grain fiber, inulin and polydextrose. *Nutr. Rev*. **69**, 9-21.

Rebello CJ, Greenway FL, Finley JW. 2014. Whole grains and pulses: A comparison of the nutritional and health benefits. *Journal of Agricultural and Food Chemistry*. **62**(29):7029-7049.

Reynoso-Camacho, R., Ríos-Ugalde, M.C., Torres-Pacheco, I., Acosta- Gallegos, J.A., Palomino-Salinas, A.C., Ramos-Gómez, M. and Guzmán-Maldonado, S.H. 2007. Common bean (*Phaseolus vulgaris* L.) consumptions and its effects on colon cancer in spraguedawley rats. *AgriculturaTécnicaen México* **33**(1), 43–52.

Ricardo-da-Silva JM, Pombo MA, Da-Silva MA. 2019. Lectins as bioactive plant proteins: A potential in the treatment of gastrointestinal diseases. *Food Research International*. **116**:823-833.

Ros E, Martínez-González MA, Estruch R, Salas-Salvadó J, Fitó M, Martínez JA, et al. 2019. Mediterranean diet and cardiovascular health: Teachings of the PREDIMED study. *Advances in Nutrition*. **10**(4):712-740.

Saxena, M., Saxena, J. and Pradhan, A. 2012. Flavonoids and Phenolic Acids as Antioxidants in Plants and Human Health. *Int. J. Pharmaceut. Sci. Rev. Res.* **28**, 130-134.

Thompson, M.D., Mensack, M.M., Jiang, W., Zhu, Z., Lewis, M. R., McGinley, J. N., and Thompson, H. J. 2012. Cell signaling pathways associated with a reduction in mammary cancer burden by dietary common bean (*Phaseolus vulgaris* L.). *Carcinogenesis* **33**, 226–232.

Tsai PJ, Li YH, Huang SC, Lin HH, Chen YC. 2017. Nutritional composition and antioxidant capacity of various colored sweet potato (Ipomoea batatas) tubers. *Journal of Food and Nutrition Research*. **5**(2):123- 130.

Uusiku NP, Oelofse A, Duodu KG, Bester MJ, Faber M, van der Rijst M. 2013. Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: A review. *Journal of Food Composition and Analysis*. **30**(2):200-209.

Viguiliouk E, Kendall CWC, Blanco Mejia S, Cozma AI, Ha V, Mirrahimi A, et al. 2014. Effect of legume consumption on blood pressure: A systematic review and meta-analysis of randomized controlled trials. *Clinical Nutrition*. **33**(2):226-232.

Wang X, Jin Z, Cai L, Xu B, Zhang Y. 2020. Optimization of the production of kidney bean flour with high protein content using response surface methodology. *Food Chemistry*. **214**:541-546.

Yadav SS, Mithal S, Beniwal R. 2020. Optimization of soaking and germination conditions for improvement of nutritional and functional properties of kidney bean (Phaseolus vulgaris) flour. *Food Science and Technology International*. **26**(3):270-281.

Yang R, Zhou T, Liu Y, Shi C, Yang B. 2021. Development and characterization of kidney bean-based snacks and convenience foods. *Journal of Food Science and Technology*. **58**(3):856-864

Zhang, H.W., Yang, M.D., and Fan, X.F. 2011. Study on modification of dietary fiber from wheat bran. *Adv. Mat. Res.* **183**, 1268-1272.

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Research Article

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Gum Arabic Producers' Opinions and Views towards Gum Arabic Marketing Policies-and Strategies, Sudan

Mohammed O. Hassan[1], Ali A. Salih[2], Ibrahim E. Ibrahim[3], Muneer Elyas Siddig Eltahir[1*], Hanan E. Alhabeeb[3] and Mohmoud A. Amassaib[3]
[1]Institute of Gum Arabic Research & Desertification Studies, University of Kordofan, P O. Pox 160, Elobied, Sudan
[2]Faculty of Agriculture, University of Khartoum, Shambat, Khartoum North, Sudan
[3]Faculty of Natural Resources & Environmental Studies, University of Kordofan, P O. Pox 160, Elobied, Sudan
**Corresponding author e-mail: muneersiddig88@gmail.com*
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ABSTRACT
The study aimed to conduct a comparative analysis of the opinions and views of gum Arabic producers towards Gum Arabic marketing policies in Sudan. Primary data were collected in 2016, using a structured questionnaire and 150 gum Arabic producers were interviewed, representing 20% of the targeted population in the study. Secondary data were collected from related official documents. Descriptive statistical analysis was used to investigate the opinions views and socio-economic characteristics of the stakeholders. The results indicated that about (97%) of the respondents preferred the free-trade policy to concession as it gives more price incentives to producers (98%), encouraging producers (98%). There are 98 % of the producers conserve and reforest instead of cutting *Hashab* trees. All the respondents confirmed the prices are higher post-free-trade than pre-free-trade period. 74% of the gum producers were economically active including the young; this indicated continuing to preserve indigenous knowledge techniques of gum Arabic production across generations. The study recommended continuing the free-trade policy in the production and marketing of gum Arabic, involving the private sector to provide credit to the gum Arabic producers to expand their gum production area. Improve infrastructure and basic services in the gum Arabic production areas
Keywords: Gum Arabic Production, marketing policies, producers' views

INTRODUCTION
Having been acknowledged as Sudan is the world's dominant leader in gum Arabic production; as it contributes to about 95% of the total world gum Arabic production (Abu Ali, 2011). It effectively controls almost 80% of the world market (Anderson, 1993; Abu Ali, 2011). Gum Arabic (*Acacia* species) is the dominant leguminous tree crop that belongs to the family *leguminaceae.* It includes over three hundred species of which *Acacia senegal* and *Acacia seyal* represent commercially traded species (Wuranti, 2010). The density of gum Arabic-producing trees varies from one area to another but the main zone of production of gum Arabic is located in West and North Kordofan States (Habish, 2012). The best gum Arabic quality is produced from *Acacia Senegal* (L.)Willdenow (*Hashab*). Most of the gum is produced by smallholders on individual farms where the trees grow. To get the gum, the tree bark is partially removed, and the gum is exuded in droplets from the wound. These droplets grow to nodules 2–5 cm in diameter and then picked. (Seifel Din and Zrroug, 1996). Gum production begins to decline when the tree is about 15 years old. When the land is taken back into cultivation, the tree is coppiced. The land is then cultivated until its fertility falls below an acceptable level. During this time most of the trees regenerate naturally by coppice growth. Three to five years after cutting, trees tapped again. (Badi *et al*, 1989). The *Acacia Senegal* tree is tapped after the end of the rainy season. The suitable time depends on the end period of rain. The best time for tapping is usually recognized by the shedding of leaves and changes in the color of the inner bark from white to red (Hassan, 2008). Tapping is practised during two different periods. Early tapping is conducted from October until the end of November. Late tapping is done only for trees in agro-forestry system where *Hashab* trees were grown and the crops were cultivated between the trees, or for those trees in water collecting sites, from December till the end of February. The tools for tapping *Hashab* trees were the traditional axe and the developed ‘Sunki (Adam *et al*, 2016). Gum exudation takes place a few weeks after tapping and is enhanced by hot weather whereas the yield of gum is delayed and decreased by cold weather. The gum is collected in several pickings depending on the time of

tapping. The first picking is collected five to six weeks after tapping. Then, the gum is collected in a series of subsequent pickings, until the end of picking season. Up to seven pickings could be reached if the tapping is done early. An average tree can yield about 100-300 grams per year. On a scattered wooded stand it was possible to collect 12-16 Kg per feddan one feddan is equal to (*.44 hectare)*, while on a densely wooded stand, the yield can increase to about 40 Kg per feddan. The peak of production is obtained from the third, fourth and fifth pickings (Taha, 2000). The gum Arabic productivity differs from one tree to another tree and from one area to another, depending on a number of environmental and socio-economic factors such as high temperature, good rainfall in quantity and distribution, suitable time for tapping, free grazing, insect pests and diseases, and good prices. Accumulated indigenous knowledge about *Hashab* husbandry represents the major support for the production potentiality and sustains the resource base (Adam *et al*, 2016)**.** Gum Arabic tree has values for non-marketable goods and services in terms of soil protection and restoration of soil fertility. Okoro (2011) cited that, gum Arabic plantations indirectly contribute to the improvement of the environment in areas threatened by desertification. The tree improves soil fertility by dropping leaves. It also fixes and stabilizes dunes and combats wind erosion. The increased density of gum Arabic plantations, they have the potential to act as shelter belts, that reduce the problems of desert encroachment, environmental degradation and poor soil nutrition. Gum Arabic is an important off-farm activity for more than 5 million of Sudan's population. In addition, producers hire entire families living in the gum belt for four months in the dry season. There was an average of 19% of household earnings come from activities related to gum Arabic (GAC, 2000). It is an important source of income in rural areas where opportunities are limited and where the workforce is often not mobile or unable to engage in more labour-intensive work. Gum collection or gathering is a source of revenue in rural areas providing income during the dry season when there is little other agricultural income (Taha, 2006). Poverty alleviation is one of the main aspects of gum production in socio-economic sustainability. Gum is a way for smallholders to diversify their livelihoods and alleviate the risk of subsistence crises (Olsson 1993). Gum Arabic is not only important for the smallholders, but also for the country of Sudan being a major source of foreign exchange. In recent years, it has accounted for about 13% of annual export earnings. For decades, gum Arabic has still one of the main agricultural exports from the rainfed agricultural area. Until the introduction of cotton in 1920, gum Arabic was the main source of export revenue in Sudan (Habish, 2012).

MATERIALS AND METHODS

Study Area:

Figure (1) gives the study area in the North and West Kordofan States. Which covers selected localities in North and West Kordofan States. North Kordofan state lies between latitudes 16˚ 38¯ N and 12˚ 14¯ N and longitudes 26˚ 46¯ E and 32˚ 22¯ E, the data in NK state was collected from Um-Ruwaba, Sheikan and Elrahad localities. West Kordofan lies between latitudes 9° 49' 29" N and longitude 27° 54' 49" E in the southern part of Sudan, the data in WK was collected from Ennuhod and Elkhwai localities. The two States are located in the heart of the Gum Arabic belt. North Kordofan State lies in the north-east part covering an area of 110483 ha, while West Kordofan State is found in the south-west part of the Kordofan gum Arabic belt covering an area of 153722 ha. The selected localities are the main production centres with a considerable contribution (60%) of the total gum of the country (Adam, 2011).

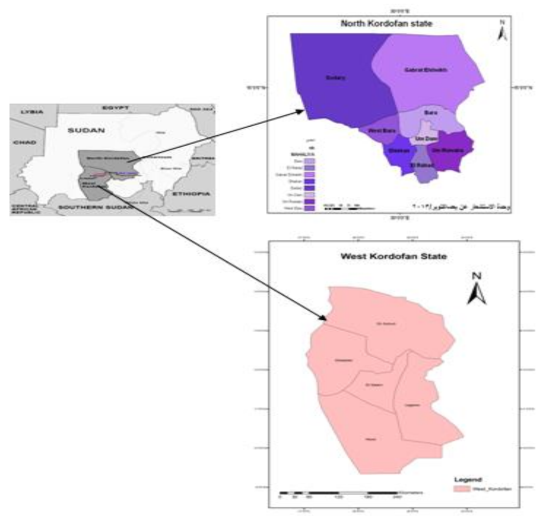

Fig 1. The North and West Kordofan States maps (Elamin and Adam, 2015**)**

According to high homogeneity of the localities in term of indigenous knowledge of gum producing techniques, the pure stand of *Hashab* trees and style of livelihood as reviewed by (ELbashir, 1999; ELkhidir, 2003; Ibrahim, 2013) households in the study area seem to be homogeneous due to the close interrelation of the various ethnic groups of farm households. They concluded that there is no wide variation to be found in lifestyles among people who live within one village, as well as among villages in the same area. Similarly, farm households in the study area are likely to be characterized by the traditional institutions subject to the regulatory rules of the tribes. Because of the homogeneity a sample of 150 producers was randomly selected.30 respondents, from each selected locality, 10% of producers for each selected village were randomly chosen from June to December 2016. Primary data was analyzed using descriptive statistical analysis (SPSS) to investigate the opinions views and socio-economic characteristics of the stakeholders.

Table 1. Sample size of gum Arabic producer

State	Locality	No. villages/ locality	Total number of producers	No. respondents (10%)
North Kordofan	Sheikan	5	306	30
	Elrahad	5	302	30
	Umrwabba	5	301	30
West Kordofan	Ennhoud	5	308	30
	Elkhwei	5	306	30
Total	5	25	1523	150

RESULTS AND DISCUSSIONS

Socio-economic Structure of Gum Arabic Producers

Table (2) gives the socio-economic characteristics of gum Arabic producers in the study area. The results indicated that all respondents were males. Recently women entered this harsh activity and established special associations in Ennuhod locality, and in other localities, their contribution appears in the picking stage. In recent years, the production of gum Arabic has become attractive to producers. Most of the respondents had ages between (20 – 60) years. About 74% were economically active, indicating that gum production was not restricted only to old producers, due to encouraging prices that ensure easy and regular transformation of indigenous knowledge of gum Arabic production techniques among successive generations. Regarding the social status of the respondents, almost all producers were married, and their family members ranged between (6-10) individuals, a source of labor for producing gum Arabic. Even though, gum orchard owners depend on themselves or hire labor more than family labor because of their limited financial ability, they share their orchard and others have the financial ability to hire labor.

The percentage of producers who studied formal education was more than the illiterate, a dominating character of producers in the past.

Table 2. Distribution of gum Arabic Producers according to socio-economic structure

Variable	Indicator	%
Gender	Male	100.0
Age	20- 60 Years	97.0
Marital status	Married	99.0
Family size	6- 10 individuals	82.0
Educational level	Illiterate	28.0
	Formal education	55.0

Distribution of gum Arabic producers by experience and tenure of gum orchards:

The production of gum Arabic has depended on indigenous knowledge about tapping trees, a technique acquired by learning by doing. About 46% of gum producers had (20 -40) years of experience in growing gum Arabic trees (table.3). Hence, the cumulative experience was a determinant factor for tapping on the right position to exude gum from gum trees. The study area was the source of this technique from which it was transferred into the other producing areas of Sudan gum belt through casual labor. With regards to the types of produced gum, all respondents produce *Hashab* gum only. This study area has a pure stand of *Hashab* trees without any mix of other producing gum trees. The *Talh* trees are the dominant trees in South Kordofan State. Moreover, the gum produced in the study area (*the Kordofan gum*) is the size of *a pigeon egg* gum pebble. It is considered the standard of gum quality not only for producing areas in Sudan, but also for all producing countries in the African gum belt as well. About 58% of the gum producers have direct usufruct ownership of their orchards, while 25% are inherited. The study area was free from land tenure conflicts. The harmony in relations among the producers was reflected in annual tapping and the smooth supply of gum to the market. From the field survey, only one orchard owner registered his orchard area officially in Elkhwai locality.

Table 3. Distribution of producers by experience, gum produced, and orchard tenure

Variable	Indicator	%
Types of produced gum	*Hashab* gum	100.0
Experience	1-20 years	37.0
	21-40 years	46.0
Types of Orchard Tenure	Ownership	58.0
	Inheritance	25.0

Distribution of the opinion of the gum Arabic Producers about the producing ages of a *Hashab* tree:

Table (4) gives information about the opinion of the gum Arabic producers about the best age for tapping the gum trees. The results in Table (4) revealed that about 82% of the producers indicated that the time for tapping gum –trees was when it is 4-5 years old and 80% indicated that the best age of a tree that gives maximum yield was when it is (10-15) years old. This period can be extended by applying the correct method of tapping, and protecting the tree against over grazing of animals, particularly camels grazing and fire outbreaks. About 68% indicated that the gum -tree gives minimum yield when it is (25-30) years old; at that age producers would cut down the trees leaving part of the tree stem to sprout for another cycle.

Table 4. Opinion of the gum Arabic producers regarding production ages of *Hashab* tree

Variable	Indicator	%
Tree age for first tapping/ years	(4-5) years	82
Tree age maximum productivity/years	(10-15) years	80
Tree age minimum productivity/years	(25-30) years	68

Distribution of opinion of the gum Arabic Producers about expanding the area and source of tapping finance

The area of tapped gum differed from one year to another. Table (5) gives the opinion of the producers of gum Arabic about the effect of last season price on expanding the area of tapping gum Arabic. The price of last year seemed to be the main factor for determining the area to be tapped next year as suggested by 77% of the respondents. The farmer allocates most of the resources towards the production of crops that had high prices in the previous season. All producers depended on self –finance as there were no sources of formal finance in the study area. Only in one village, named Abu Ismaeil, the gum producers had gum producer association financed by the Revitalizing Gum Arabic Production and Marketing Project as a revolving fund. The source of self-finance comes either from field crops or livestock revenues.

Table 5. Opinion of the gum Arabic producers regarding expanding their area and source of tapping finance

Variable	Indicator	%
Factors affecting the expansion of the tapping area	Last season price	77.0
Source of tapping finance	Self- finance	90.0
Source of self- finance	Crops revenue	60.0
	Livestock revenue	11.0

Marketing value chain, paying of taxes, levies and Zakat

Table (6) demonstrates the time of gum Arabic selling. All of the gum producers sold their gum immediately after picking. The producers did not store gum because any delay in selling decreases the weight. Therefore, they try to get rid of it promptly and sell at the current price irrespective of whether it is rewarding or not. Furthermore, gum producers did not have any other use for gum Arabic. About 42% of the producers sell gum to village traders and 30% to the middlemen. They later buy the gum in weekly markets (*Um dawarwar*: a *weekly market that revolves among villages throughout the days of a week*) on the day of the village market or in the nearest villages. Few sold in the nearest city to their villages, their main market the city itself such as Elobied with its surrounded villages. The producers are price takers and lack bargaining power. The traders determine gum prices in the market based on expected export prices, set of paid taxes, fees and Zakat on behalf of the producers.

Table 6. Gum Arabic producers' information on the marketing value chain, paying of taxes, levies and Zakat

Variable	Indicator	%
Time of selling produced gum	Immediately after collection	99.0
Channels of gum selling	Village trader	42.0
	Middlemen	30.0
Determination of selling price	The Traders	92.0
Paying of taxes& levies by producers	No	100.0
Paying of Zakat by producers	No	100.0

Distribution of the producers of gum Arabic by their response to price incentives during the concession and free trade stages:

Table (7) shows the opinion of the gum Arabic producers about the incentive status of gum Arabic prices during the pre-and post-free- trade in Sudan. The question posed to find out to what extent the removal of the concession of gum Arabic company succeeded in creating price incentives, for producers of gum Arabic. From the table it was found that almost all the producers of gum Arabic were satisfied by the new pricing system. They confirmed that those prices gave incentives and added to their income in production activities.

Table 7. Distribution of the producers of gum Arabic by their response to price incentives during the concession and free trade stages

Variable	Indicator	%
Prices give incentives	Yes	98.0
	No	02.0
Gum Arabic prices are rewarding	Yes	98.0
	No	02.0
Gum Arabic prices are higher	Yes	100.0
Gum Arabic prices are encouraging	Yes	99.0
	No	01.0
Increase in income	Yes	99.0
	No	01.0

Distribution of producers' information on the unwillingness and capacity of traders to purchase, and the impact of abolishing concession:

Table (8) indicates the problems that faced gum Arabic producers during the concessionary stage. They faced the unwillingness of traders to purchase gum despite large supplied quantities. The supplied quantities were sometimes beyond the capacity of traders to purchase due to a shortage of liquidity. With the removal of the concessionary system in 2009, all interviewed producers confirmed that traders did not have an objection to purchasing gum Arabic when displayed in the different markets. Similarly, almost all gum producers confirmed that the traders had not refused to buy from the producers due to a shortage of liquidity. The interviewed producers assured that there was no negative impact on gum Arabic production operations.

Table 8. Distribution of producers' information on the unwillingness and capacity of traders to purchase and the negative impact of abolishing concession

Variable	Indicator	%
Traders unwilling to purchase displayed gum product	Does not exist	100.0
Traders' capacity to purchase gum Arabic due to shortage in liquidity	Exists	01.0
	Does not exist	99.0
Negative impact of abolishing concession on gum production	Found	12.0
	Not Found	88.0

Distribution of producers' information on cutting and conservation of gum trees and preference system for gum marketing:

In Table (9) during the concessionary stage producers used to cut down the *Hashab* tree as it was unprofitable to produce gum. They allocated the land for cultivating field crops and producing charcoal. During the free - trade situation almost all of the producers declared that they stopped cutting the trees completely. In contrast, the producers substituted the cutting trees with the conservation of *Hashab* trees and reforestation due to price incentives. This activity was seen in all producing areas in the study area. The producers in Ennuhod and Elkhwai localities come to the Forest National Corporation (FNC) demanding *Hashab* seeds and seedlings. The rehabilitation of *Hashab* forest project in Sheikan locality started in many Gum Arabic producing villages such Botti, Um jumod and Elhimera in previous year. The free- trade policy assisted in resolving the main problems that faced the gum producers. In Ennuhod locality one of the old producers stated that when in the orchard they do not tie their donkeys to the small growing shrubs of *Hashab* trees to avoid damaging or pulling out the growing trees. This indicates the producers' awareness about tree conservation in their orchards. Almost all the producers preferred the free – trade system to the concession ones.

Table 9. Distribution of producers' opinions on cutting, conservation of gum trees and preference system for gum marketing

Variable	Indicator	Valid percent
Continued cutting of gum trees	Continued	03.0
	Stopped	97.0
Continued conservation of gum trees	Found	98.0
	Not found	02.0
Preference for concession or free trade gum Arabic marketing policy	Free trade	97.0
	Concession	03.0

CONCLUSIONS AND RECOMMENDATIONS:

Gum Arabic product remains the major and important commodity of all non- wood forest products and of the main cash crops in Sudan. It has plenty of socio-economical, commercial and environmental benefits. It plays an economic role in the economy, in terms of income source for more than five million Sudanese households, and foreign currency earnings. The policies of gum Arabic marketing witnessed many changes since the colonial era. The production of gum Arabic was led by foreign marketing, in the beginning and then turned to national marketing under the concession era, and now is liberated. The gum Arabic sector in Sudan witnessed a revival and development in production, aspects. The free- trade policy declarations embodied It was apparent the real price of gum products and hence encouraged the producers to increase gum production and conserve the *Hashab* tree. The preference of the producers the free – trade policy to the concession, this confirmed by the traders did not have objection to purchasing gum Arabic when displayed in the different markets and also explained traders had not refused to purchase because of shortage of liquidity. The producers got the rewarding share of 49% of FOB price of gum Arabic against GAC, (4% - 18 % of FOB price). Most of the revenue was monopolized by the company. The private sector was able and ready to finance regularly the purchase of supplied gum into the market. Moreover, some partnerships have been developed between exporting companies and producers to finance gum producers in the tapping period. The producers confirmed the absence of negative impacts on gum production or marketing that resulted from the abolishment of the GAC concession. The study recommended continuing the free-trade policy in the production and marketing of gum Arabic commodities, involving the private sector to provide credit to the gum Arabic producers to expand their gum production area. Improve infrastructure and basic services in the gum Arabic production areas. Establish border trade in gum Arabic. Observe gum Arabic quality across the different value chain points.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Abu-Ali, A. Abdelmajid 2011. Economics of gum Arabic production and marketing in Elgadarif State – Sudan PhD thesis –Department of Agricultural Economics- Faculty of Agriculture- University of Khartoum.

Adam, H. E. 2011. Integration of remote sensing and GIS in studying vegetation trends and conditions in the *Gum Arabic* belt in North Kordofan, Sudan, PhD thesis Berliner Verlag, Germany, ISBN 978-3-941216-58-7.

Adam, Hassan, E., Muneer E. S. Eltahir, Mohamed T. Elhaja, Osman E. A. Abdelkareem, Zeinab M.

Hammad, Awad Elkarim S. Khalifa, Tarig E. Mahmoud, Mohamed E. O. Elsayed, Hatim M. A., Elamin, Mohamed E.Taha, Abdelateif H. Ibrahim 2016. Management of Gum Arabic Production Potentialities in the Gum Belt, Kordofan.

Anderson, D.M.W. 1993. Some Factors Influencing the Demand for gum Arabic (*Acacia senegal* (L) Willd.) and other Water-soluble Tree Exudates. *Forest Ecology and Management* **58**: 1-18.

Badi, K.H., Ahmed A.E.H. and Bayoumi A.A.M.S. 1989. The Forests of the Sudan. Agricultural Research Council, Khartoum, Sudan, 184 pp.

EL-Bashir, H. 1999. Social Structure, Ethnic Relations and Land Tenure Systems in Rura Sheikan Province. Consultant Report Produced for ADS, El-obeid, Sudan.

Elkhidir, E. E. 2003. Economic Efficiency of Sharecropping in Drylands: A case Study of gum Arabic Production in Kordofan Gum Belt, Sudan. Ph.D. Thesis, University of Putra Malaysia, Malaysia.

GAC. "Gum Arabic Company" 2000. Recent indicators for gum Arabic production. A study conducted by GAC research Unit, Khartoum, Sudan.

Habish E. M. 2012. the Determinants of the Gum Arabic Producers Participation in the Gum Industry of Sudan PhD thesis Dept. of Agricultural Economics, University of Baheri- Khartoum Baheri- Sudan.

Hassan, M. O. 2008. Assessment of Gum Arabic Marketing System in Main Auction Markets of North Kordofan, M.Sc. Thesis University of Khartoum- Sudan.

Ibrahim, A. H. 2013. Impact of Microcredit on Poverty Alleviation in Rural Sudan: An Applied Modeling Approach in North Kordofan, Central-west Sudan PhD thesis Dept. of Agricultural Economics and Social Sciences in the Tropics and Subtropics, University of Hohenheim, Germany.

Okoro, C. 2011: Gum Arabic production and marketing in Nigeria. Nigeria Economic Summit Group NESG, Agricultural summit, pp.60-36.

Olsson, L. 1993. On the causes of famine-drought, desertification and market failure in the Sudan. *Ambio* **22**: 395–403

Seif el Din, A.G. and Zarroug M. 1996. Production and commercialization of gum Arabic in Sudan. In: FAO (eds), Re-port of the International Expert Consultation on Non-Wood Forest Products: Yogyakarta, Indonesia, 17–27 January1995.Food and Agricultural Organization, Rome, Italy, pp.465, 1–7.

Taha, M. E. 2006. The Socio-economic role of *Acacia senegal* in sustainable development of rural areas in the gum belt of the Sudan, ISBN 3-9809816-6-6.

Taha, M. N. 2000. The Socio-Economic Role of *Acacia senegal* in Sustainable Development of Rural Areas in the Gum Belt of the Sudan. PhD Dissertation, Institute of International Forestry and Forest Products, Technical University of Dresden, Germany.

Wuranti, Valla 2010. Resource use Efficiency in gum Arabic production among farmers in Yobe State, Nigeria Kogi State University, Anyigba, Kogi State, Nigeria -International Journal of Food and Agricultural Economics ISSN 2147-8988 Vol. 2 No. 1 pp. 77-84 77.

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Research Article

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Assessment of the impact of native tree species reforestation in Rwanda. A case study of Ibanda makera natural forest

Gaspard Ntabakirabose[1], Innocent Hakuzimana[2], Vital Mory Karinda[3], Jean Claude Noel Majuga[4], David Mwehia Mburu[5]
[1,2]Department of Forest Research, Rwanda Forestry Authority, Huye, Rwanda
[4]Department of Agricultural Engineering, Integrated Polytechnic Regional College (IPRC) Musanze, Rwanda.
[5]Department of Land Resources Planning and Management, College of Agriculture & Natural Resources, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya
**Corresponding author e-mail: gmutago@gmail.com*
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ABSTRACT
The study was conducted in Kirehe District, Mpanga Sector. The major objective of this study was to assess the impact of native tree species reforestation in Rwanda. A Case Study of Ibanda Makera Natural Forest. The study adopted a cross-sectional survey research design as its framework to guide the process of data collection. The target population was households living closer to the forest. The study adopted a purposive sampling approach to select four villages. Twenty (20) households were randomly selected from each village making a total sample size of 80 respondents. Descriptive analysis was done using SPSS version 20, and regression using STATA version 17. A logistic regression model was mostly adopted for this study to determine the factors influencing native tree species in the study area. The result of the regression analysis indicated that age, gender, occupation, household size, price of fuel, tree product use, and distance to the forest influenced negatively native tree species. This study revealed that the most common social-economic benefits of native tree species reforestation are community benefits, soil protection, carbon sequestration, increased research activities, habitat restoration, climate resilience, job creation, water regulation, increased tourism demand, and infrastructure development. Additionally, native tree species require less maintenance, are more tolerant of local conditions, and require fewer pesticides and fertilizers to thrive. Native tree species often require less water and can be used to create natural buffers that reduce noise and air pollution. Finally, from an economic perspective, native plants can improve property values, reduce energy costs, and create a more desirable living environment. Native tree species may also reduce the risk of invasive species, which can be costly and difficult to remove. Policymakers and planners should consider the importance of incorporating native tree species into their plans to ensure a more sustainable and resilient of native tree species for both urban and rural natural environments.
Keywords: Assessment, Impact, Native Tree Species, Reforestation, Natural Forest

INTRODUCTION
More than 94% of the Rwandan population depends on wood as a source of energy. Improved management of forests through afforestation and reforestation helps to diversify income-generating activities. Rwanda remains a predominantly agrarian society and much of the energy use consists of firewood and charcoal (MININFRA,2008a). 86% of overall energy use is biomass-based in the form of firewood (57%), charcoal (23%) or agriculture residues (6%). The remaining 14% of non-biomass energy is derived from petroleum products GE Baseline Survey Report - Rwanda 2016 12 (11%) and electricity (3%) (GoR, 2016). The increase in the frequency of natural disasters due to climate change observed in the environment in recent years has led people to understand the importance of tree. With an intent to combat climate change, the Rwandan government has been pursuing reforestation and afforestation through many programs across the country to increase forest cover (MININFRA,2008a).

One of the major issues associated with the afforestation and reforestation activities in natural and urban habitats is the introduction of exotic species especially Eucalyptus species which were introduced for greening the area(Charles and Dukes,2007). These species sometimes become potential threats as they become invasive, outcasting the natural vegetation and further negatively affecting ecosystem services upon which human societies depend (Charles and Dukes,2007). The invasive species becoming a potential threat can pose several other ill effects such as causing toxicity and allergic reactions (Nentwig *et al.,* 2018), and

homogenizing biotic communities by replacing native species (Ku¨hn and Klotz, 2006).

Reforestation involves the replanting of trees in areas that have been previously deforested. It is a crucial strategy to mitigate the impacts of deforestation (Akpan-be, Isidore Nelson, 2017), and (Ngounou Boris,2021).

Reforestation involves the deliberate planting of trees and restoring forested areas that have been depleted or destroyed. It involves a planned forest restocking to ensure a sustainable supply of timber and other forest products (Akpan-be, Isidore Nelson, 2017), and (Ngounou Boris,2021). Reforestation, in essence, involves replenishing forests to guarantee a consistent and sustainable supply of timber and various other forest resources. This objective can be accomplished through either natural regeneration techniques or artificial regeneration methods (Akpan-be, Isidore Nelson, 2017).

Reforestation generally has many advantages of supporting various flora and fauna and promoting ecological balance. Forests play a crucial role in absorbing carbon dioxide from the atmosphere and act as carbon sinks. Sequestering carbon reduces greenhouse gas emissions. Reforestation helps prevent erosion by stabilizing soil, reducing runoff, and promoting humus production from organic matter *in situ* (Park Chris *et al.*,2017). Forests play a vital role in regulating water cycles and maintaining healthy watersheds. Reforestation helps protect water sources, improves water quality, and reduces the risk of flooding, benefiting both urban and rural communities (Park Chris *et al.*,2017). Reforestation and afforestation promote the sustainable management of forest resources, including timber, non-timber forest products, and medicinal plants(Park Chris *et al.*,2017).

Reforestation can help reverse some of the more severe impacts of forest loss and degradation on rural communities in the tropics by providing secure access for local people to a range of forest products, including fuelwood and non-timber forest products; improved hydrological regulation and nutrient cycling; providing more diverse and better-connected habitats, thus supporting more biological diversity; and options to increase the resilience and adaptability of existing agricultural systems (Maginnis and Jackson, 2002).

For reforestation to be attractive to local communities, it needs to provide socio-economic benefits. As a pre-requisite for achieving long-term reforestation success, local people must receive benefits exceeding those from alternative land uses, otherwise reforested areas will continue to be cleared (Ramakrishnan *et al.*, 1994).

One of the major problems facing Worldwide forests including Rwandan forests is the shifting cultivation of farming, which reduce forests. Shifting cultivation is a method of farming in which a farmer relocates his farm to another place after about three years, as a result of the decline in crop yield. The row cropping system may be an alternative to shifting cultivation. The row-cropping method involves a compromise between row-cropping and forestry. It involves the growing of food crops and forest crops together, as long as the forest crops allow sunlight to penetrate and reach the food crops. Through this system, the land will be in continuous production, providing income to farmers and at the same time preserving the ecosystem (Etuk, and Collins, 1976).

According to the CIFOR Rehab Team (2003), the objectives of reforestation projects are to enhance productivity, livelihood, and environmental service benefits. In general, the objectives of reforestation projects are divided into physical and non-physical. Physical objectives are usually aimed at increasing forest and land cover, increasing timber production, protecting watersheds, and conserving biodiversity; while the non-physical objectives are usually to increase community incomes, create livelihood opportunities, empower local communities, secure community access to land, and to raise environmental awareness and education (Chokkalingam *et al.*, 2006a; Nawir *et al.*, 2007).

The socio-economic benefits of reforestation do not necessarily have to be direct and can include 'avoided negative impacts' (e.g. landslide prevention or preservation of timber reserves) (Akindele, S.O, 2012). The most common indicators used for measuring the socioeconomic success of reforestation are local income, local employment opportunities, other livelihood opportunities, provision of food and fiber, stability of market prices of locally produced commodities, and local empowerment and capacity building (Akindele, S.O, 2012).

However, reforestation initiatives in Rwanda face many obstacles. Among these challenges is the inability of the country to maintain a basic standard of acquiring regular and up-to-date information on its forest reserves. Most of the information used in making decisions on Rwandan forests is based on obsolete information and extrapolation from very old data (Akindele, S.O, 2012).

In Rwanda especially in the Eastern province, several species of native trees are found there. One such trees are *Erythrina abyssinica* (Umuko), *Ozoroa reticulate* (Umukerenke), *Zanthoxylum chalybeum* (Intareyirungu), *Albizia Amara* (Umunaniranzovu), *Euclea schimperi* (Umushikiri), *Combretum molle* (Umurama), Dombea sp (Umuhanga), (*Acacia polyacantha (*Umuharata), etc. are known for their medicinal properties and ability to purify the air. The global objective of this study was to assess the impact of native tree species reforestation in Rwanda. A Case Study of Makera Natural Forest. By planting and conserving native trees in Rwanda, we can help create a more sustainable and healthier environment for future generations.

The species of tree selected for reforestation can have a large influence on both the benefits derived from tree products and the ecological benefits of the forest (Montagnini, 2005). The most important socio-economic requirements for reforestation success appear to be enhanced livelihood planning, active participation and involvement of local people, payment for environmental

services provided by forests, socio-economic incentives, financial and economic viability, degree of dependency on traditional forest products, social equality, absence of corruption, marketing prospects, and addressing underlying causes of forest loss and degradation (Dudley *et al*., 2005).

The native species, which are well acclimatized to the local environment, on the other hand, help in providing undisrupted ecosystem services. All the lower and higher level of animal species depends on the native tree species of the region for their food requirements, shelter, etc. Most importantly the native plant species does not require additional needs of resources for its growth and maintenance. In short, native species not only support ecosystem services but also support the native fauna of the region. Therefore, to keep the ecological balance of an area it is very important for planners to safeguard the existence of native plants and should promote less of the exotic plants for the plantation in the natural and urban landscapes. However, the promotion of native tree species in the long run, with mixed plantations can lead to the development of a healthy natural ecosystem (Andrew David Almas; Tenley M. Conway, 2017). As native trees are an essential part of our ecosystem and play a critical role in maintaining the ecological balance of our planet. They provide numerous benefits, such as improving air quality, reducing soil erosion, and providing habitat for wildlife. These trees are particularly important because they are well adapted to the local environment, and therefore require less maintenance and resources to grow and thrive (Andrew David Almas; Tenley M. Conway, 2017).

Few studies have been conducted on native tree species identification, benefits, breeding, methods of harvesting, dissemination, propagation, and other factors as well as challenges of adoption in many countries including Rwanda. Therefore, the main aim of this study was to assess the impact of native tree species reforestation in Rwanda. A Case Study of Ibanda Makera Natural Forest to encourage the planting of native trees. Specific objectives of the study were to classify the native tree species threatened in the study area; to identify the factors influencing native tree species threatening in the study area; and to determine the social-economic impact of native tree species reforestation in the study area. By planting and conserving native trees in Rwanda, we can help create a more sustainable and healthier environment for future generations.

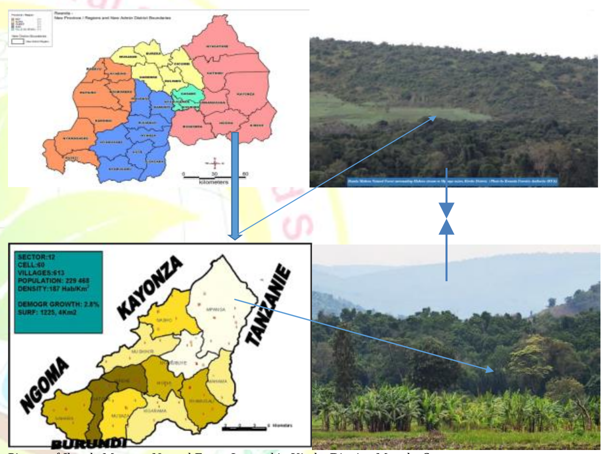
MATERIALS AND METHODS

Study Area:

Description of the Study Area

The Rwanda Population and Housing Census 2022 revealed that the total population of Rwanda is spatially distributed in rural areas representing 72.1% and urban areas representing 27.9%. The Eastern Province is predominantly the urban area (86.9%) and rural area (13.1%). Kirehe District population is predominantly by rural area 93.7% while urban represents 6.3%. Kirehe district has a current population density of 398 inhabitants/km2. It is made up of twelve administrative sectors, which are: Gahara, Gatore, Kigarama, Kigina, Kirehe, Mahama, Mpanga, Musaza, Mushikiri, Nasho, Nyamugali and Nyarubuye, 60 cells and 612 administrative villages (NISR,2022).

Kirehe Flora, a shrubby savannah dominates the natural vegetation of the district of Kirehe. The fauna of Kirehe district is diverse with several birds, reptiles, amphibians, insects, and aquatic animals including fish, crocodiles, and hippos. A large part of the fauna of Kirehe is located in the inhabited places. Kirehe District has forest plantation estimated to be 2,634 Ha of woodlots, planted by the local gaovernement and those belonging to private individuals. The Forestry sector plays a key role in supporting the livelihood of all Rwandans, especially by providing most of the energy consumed by the bulk population, controlling soil erosion protecting water catchments, and supplying other goods and ecological services (REMA, 2015).



Picture of Ibanda Macyera Natural Forest Located in Kirehe District, Mpanka Sector.

Research Design

Research design provides a logical structure for research data gathering and analysis. The study adopted a cross-sectional survey research design as its framework to guide the process of data collection.

Target Population, Data Collection, and Sampling Procedure

The target population was households living closer to the forest. The study adopted a purposive sampling approach to select four villages (Nyawera I, Nyawera II, Pirote, Busasamana I) of Nasho cell of Mpanga sector in Kirehe district of Eastern Province. These villages were purposively selected based on the proximity to the Macyera forest which was the study area. The respondents were stratified into one category namely forest communities. Twenty (20) households were randomly selected from each village making a total sample size of 80 respondents. Data was collected between October-November 2023 through personal interviews, and structured questionnaires.

Table 1. Sample Size Distribution.

Location/ District	Village	Sample size
KIREHE	NyaweraI	20
	Nyawera II	20
	Pirote	20
	Busasamana I	20
TOTAL		80

Data Analysis

The study used structured questionnaires to obtain information from the respondents. The data was coded and entered in the Statistical Package for Social Scientists (SPSS). Descriptive analysis was done using SPSS version 20, and regression using STATA version 17. The analysis included assembling of tables, and a logistic regression analysis to identify the factors influencing native tree species threatening in the study area

Model Specification

To determine the factors influencing native tree species threatening in the study area, a logistic regression model was mostly adopted for this study. The study regressed the factors influencing native tree species threatening in the study area as the dependent variable as a function of the independent variables which are socioeconomic and demographic. The choice of the logistic regression model is premised on the specification of the dependent variable as binary in nature and outcome.

Logistic Regression

Following Maddala (1983, 2001), the probability, *p*, that a household uses native tree is given by:

$$P = \frac{e^{z}}{1+e^{z}}$$

Central to the use of logistic regression is the logit transformation of p given by Z

$$Z = \ln\left(p \big/ 1-p\right)^{2}$$

Where;

$$Z = Z\left(f, d, a\right) + \varepsilon$$

Z is a latent variable that takes the value of 1 if the household used native tree and 0 otherwise, f is a vector of farmer characteristics, d is a vector of farm level variables, a is a vector of asset endowment variables, and ε is the stochastic term assumed to have a logistic distribution. Based on the above equation, the logistic regression model was estimated using multiple regression analysis.

Estimated Logistic Model

Specifications of the Empirical Model used for the native tree (Z) = f (age, household size, educational level, major occupation, medicinal use experience, gender, marital status, distance forest) + e

Specifically, the empirical model is specified as:

$$Y = \beta0 + \beta1\ X1 + \beta2\ X2 + \beta3\ X3 + \beta4\ X4 + \beta5\ X5 + \beta6\ X6 + \beta7\ X7 + \beta8\ X8 + \beta9\ X9 + e$$

Where:

Y represents the total native tree products demanded in stere (st)

X1= Age (years)

X2 = Household size (number of persons in the household)

X3 = Educational level (years spent in school)

X4 = Major occupation (Dummy, farmer = 1, off-farming = 0)

X5 = Medicinal use experience (years)

X7 = Gender (Dummy, male = 1, female = 0)

X8 = Marital status (Dummy, married = 1, other = 0)

X9 = Distance to forest (km)

e = Error term

β0 = Intercept

RESULTS AND DISCUSSIONS

This study discussed the results and findings as well as linkage to the previous parts. The first results relate to the sociodemographic characteristics of households surveyed within the selected sectors/communities under study as shown in Table 1.

3.1 Socio-economic Characteristics of the surveyed Respondents

The data collected from the respondents were used to run regression analysis as well as to find out the relationship between inputs and the output. The results obtained are shown in the table 2 below.

Table 2. Socio-economic characteristics of surveyed respondents.

	Frequency	Percentage
Gender		
Male	46	57.5
Female	34	42.5
Age		
21-30	11	13.75
31-40	20	25
41-50	35	43.75
>50	14	17.5
Family size		
1-3	20	25
4-7	47	58.75
8 and above	13	16.25
Education		
Illiterate	17	21.25
Primary	32	40
Secondary school	20	25
University	11	13.75

The study indicated that 57.5% of the respondents were male and 42.5% were female. This implies that most of those who participated were male head of household and are most likely to be participating in forest product use especially in building, charcoal preparation, hunting as well as medicinal practices. However, 42.5% were female participating in cooking using firewood form the nearest forest even in said one. The findings displayed that 43.75% of the respondents are between 41-50 years followed by 25% whore are in the range between 31-40 years. The third class is 50 years and above with 17.5%. The last class was that is between 21-30 years with 13.7%. The findings showed that 58.7% of the respondents are between 4-7 members of household followed by 25% who are between 1-3 members while

the last class was occupied by eight and above members per household with 16.2%. The results indicated that 40% attended primary school, followed by 25% of those who attended secondary school and the who attended university. The results showed that the illiterate class was occupied by 21.2% which is less compared with those in attended school. However, this percentage of the illiterate class will have a negative impact on forest conservation through household food preparation using firewood and lack of capacity building for tree harvesting and forest conservation and management.

The native tree species threatened in the study area

When a forest is cut down, the humidity levels come down and cause the remaining plants to dry out. Forest loss and degradation are both cause and effect of our changing climate. Additionally, loss of trees leads to flooding, soil erosion, desertification, loss of biodiversity, food insecurity in the future, and an increase in global warming and higher temperatures to occur more rapidly and exponentially. This also contributes to social economic conflict and population migration. This investaigation, the native tree species threats were categorized into six main classes such as firewood, animal grazing, medicine, buildings, food, and others. The findings of this study revealed the first class for native tree species threats was the firewood (96.75%) followed by animal grazing with (72.5%), medicine (53.45%), building (27.8%), food (8.7%), and others with (15.9%). Human activities have been viewed as one of the major sources of the environmental degradation. Ibimilua(2012) supported that deforestation is caused by human induced activities. Forest encroachment through various human activities are a threat to Rwandan forests. These activities include illegal logging, charcoal production, and bushfires. A national forest inventory in 2007 identified illegal tree cutting (78.3 %), charcoal making (4.9 %), livestock grazing (2.5 %), farming activities (1.9 %), bushfires (1.9 %), stem debarking (0.6 %), mining (0.5 %) and beekeeping (0.4 %) as the main threats (MINITERE-ISAR 2007).

In the study area, respondents indicated that the firewood (96.75%) for example *Dryptes gerrardi* (Umunyagahira), *Coffea eugonioides* (Umushangura), *Pterygota mildbraedii* (Umuguruka), *Acacia polyacantha* (Umuharata), *Pittosporum spathicalyx* (Umunyerezankende), *Markhamia obstifolia* (Nyiragasave), *Vachellia sieberiana* (Umunyinya) etc are in the first class. This is because the local community are mainly dependent on forest products particularly firewood for cooking. The result of this study is in line with GE Baseline Survey Report of Rwanda in 2016 indicated that Biomass Energy consumption is estimated at 86% as national average but at the district level, it is estimated at 96.3%. Fuel wood consumption is estimated at 3.2 million tons per year (GoR, 2016).

The results showed animal grazing with (72.5%) as the second main class for native tree species threats in the study area. This is because the local community did not yet adopt the system of zero grazing. This was supported by Hassan and Hertzler (2012) postulated that overgrazing, the extensive removal of tree cover for dry-land farming (both mechanized and traditional), and the excessive cutting of wood resources for fuel purposes are the main causes of deforestation in arid and semiarid environments.

The use of forest products as medicine occupies the third class which increased native tree species threats in the study area because main species for instance *Osylis lanceolate* (Kabaruka), *Comretum sp* (Umumuna), *Zanthoxylum chalybeum* (Intareyirungu), *Securidaca longepedunculata* (Umunyagasozi), *Grewia similis* (Umukomagore), *Albizia amara* (Umunaniranzovu), etc. are used to cure different human and animal diseases. The class of others with (15.9%) also cause native tree species threats in study area because they are used in Rwandan natural tools/instruments such as *Ficus thonningii* (Umuvumu), *Cordia Africana* (Umuvugangoma), *Albizia gummifera* (Umusebeya), *Markhamia lutea* (Umusave), *Olea europea var Africana* (Umunzenze), *Teclea nobilis* (Umuzo), and *Polyscias fulva* (Umwungo) are used to make chairs, spatula, wooden ladle, mortar for pounding, walking stick, milk pot, trough, bowl, drums, pipe, dugout, paddle, and other ornamental handcrafts materials.

Figure 1. Classification of native tree species threats in the study area

The factors influencing native tree species threatening in the study area

The data collected from the respondents were analysed using a multiple regression model to determine factors influencing native tree species threats in the study area. R-square value (R^2) of 0.7245 means that 72.45% of the total variation in factors influencing native tree species threatening explained the dependent variable. The result of the regression analysis in (Table 3) revealed that seven variables out of ten negatively influenced native tree species threatening in the study area. Age, gender, occupation, household size, price of fuel, tree product use, and distance to the forest influenced negatively native tree species threatening.

Meanwhile, household size, price of fuel, and distance from the forest were negatively significant at the $P \leq 0.01$ level. This implies that a unit increase in household size, and price of fuel will lead to increased native tree species threatening by 1.4 and 3.7 units respectively. However, a 1 km distance decrease to forest will lead to increased native tree species threats by 1.8. This was supported by

Belete Limani Kerse (2016) in his study on factors affecting local People participation in forest managed for carbon sequestration a Case of Mount Damota, Southern Ethiopia which indicated that distance from forest should negatively increase forest degradation because further a household is from the forest resource, the less it will interact with forest.

However, age, gender, occupation, and tree product use were negatively statistically significant at $P \leq 0.05$ level. Moreover, only three variables such as education level, off-farm income, and land size influenced positively native tree species threatening. This for instance implies that a 1-year increase in the level of education of the respondent will lead to reduce native tree species threatening by 0.85%. This study is in the same line with that of Faham *et al.*, (2008) concluded that the level of forest dweller participation in forest management activities increase as their level of formal education increases.

The results of the study showed that a unit increase in the off-farm income generation, and land size will lead to reduced native tree species threatening by 0.56 and 0.36% respectively. The finding is consistent with Chhetri (2005) indicated that the households head with larger land size have low intensity of participation in natural forest activities rather than being concentrated in their own farm activities. This could be due to the fact that the large land enabled them to have enough fodder, ground grass and other forest related benefits they could have got.

This could be because education helps the rural communities to understand better the innovation introduced to them as regard forest conservation and management as well as both direct and indirect tree production help them to make sound and useful economic and managerial decisions.

The level of education also determine the quality of skills of local communities, their allocative abilities, and how well-informed they are about the innovations and technologies around them. This is because people with higher educational qualification are usually faster adopters of innovation in different domains. This was supported by Nawir *et al.*, (2007) indicated that agriculture leads to around 80% of deforestation. Due to the over rowing demand for food products, a huge number of trees is clear felled to grow crops, and 33% of agriculture-caused deforestation is because of subsistence agriculture. This was also supported by Nawir *et al.*, (2007) which notes that industrial activities are the principal driver of deforestation and degradation worldwide, but subsistence agriculture and fuelwood consumption remain an important direct driver of deforestation, especially in Africa. Drivers vary on a regional scale. For example, cattle ranching and large-scale agriculture are major drivers of deforestation in Latin America, whereas palm oil development, intensive agriculture, and pulp and paper plantations are principal drivers in Indonesia.

The results showed that there is a negative influence of tree product use and native tree species threats in the study area at ($p< 0.05$). This implies that a unit increase in tree product use would increase native tree species threatening by 0.97 units. This is for example the construction of family houses, animal shade, bridges, firewood, charcoal, timber, medicine, and fodders are undertaken to increase the rate of native tree species threatening. Therefore, forestland is reclaimed. The results also pointed out that there is a significant association between household size and native tree species threats in the study area at ($p< 0.01$). This implies that a unit increase in the household size would increase native tree species threatening by 1.4 units. This is because household size requires more forest products for construction of house, firewood for cooking, etc. This was supported by Mfon, *et al.*, [25] in their study in Nigeria who have identified population growth and its resultant effect on deforestation. This is because as the population grows, it increases the pressure on the available forest resources for sustenance and survival. In addition, population growth also increases the demand for housing and construction, which results in a general forest decline.

Increases in human population are likely to increase household size and this could lead to an increase in fuel wood dependence in developing countries. Kapinga [22] argued that the majority of these households who depend on the forest for their livelihood are from the rural periphery of the developing countries and this has led to deforestation as a common feature.

Table 3. Regression analysis of factors influencing native tree species threats

Explanatory variables	Coefficient	Standard deviation	p-value
Age	-0.159	0.103	0.012
Gender	-0.287	0.262	0.043
Education level	0.854	0.105	0.000
Land size	0.367	0.679	0.075
Occupation	-0.448	0.113	0.035
Off family income	0.568	0.318	0.019
Households size	-1.431	0.362	0.000
Price of fuel	-3.66	0.020	0.003
Tree product use	-0.975	0.082	0.015
Distance to forest	-1.828	0.624	0.008
constant	3.097	3.766	0.000
Number of observations = 80, Prob > Chi2 = 0.000 Log likelihood = -43.75, Pseudo R2 = 0.7245			

Social-economic impact of native tree species reforestation in the study area

Forests fulfill far more functions than simply the production of wood and non-timber forest products. Indeed, they are vital in achieving global sustainable development. They provide solutions to challenges including poverty eradication, environmental sustainability, food security and agriculture, energy, clean water and watershed protection, biodiversity conservation, mitigation of and adaptation to climate

change, combating desertification and land degradation, and disaster risk reduction (Kühn, 2006).

However, the findings of this study revealed that the most common social economic benefits of native tree species reforestation were the Community benefits (100%), Soil protection (97.5%), Carbon sequestration (93.7%), increase research activities (73.75%), Habitat restoration (71.25%), Climate resilience (63.75%), jobs creation (53.75%), Water regulation (43.25%), Increase tourism demand (37.5%), and infrastructure development (23.75%).

In the study area, all respondents (100%) reported that the native tree species reforestation provide the community benefits. This is because the native tree species reforestation provides community benefit in different domain as listed in figure 2. For example, jobs creation, soil protection, infrastructure development, research activities etc. This is because native tree species reforestation can provide economic opportunities for communities through sustainable forestry practices, as well as supporting ecotourism.

The native tree species reforestation is very important because it helps to sequester carbon from the atmosphere, reducing greenhouse gas concentrations and the results showed that (93.7%) respondents were agreeing with this benefit. Furthermore, native tree species reforestation provides habitats for a wide range of species, helping to restore biodiversity. The native tree species reforestation is very crucial because trees help stabilize soil, prevent erosion and maintain soil fertility as well as increase agricultural and forest productivity. The results of the study showed that native tree species reforestation facilitate water regulation as forests play a vital role in regulating water flow in rivers and streams, reducing the risk of floods and ensuring a steady water supply. The results of the study revealed that native tree species reforestation is incomparable reason and important forest management activity because a well-planned reforestation effort can enhance the resilience of ecosystems and communities to the impacts of climate change.

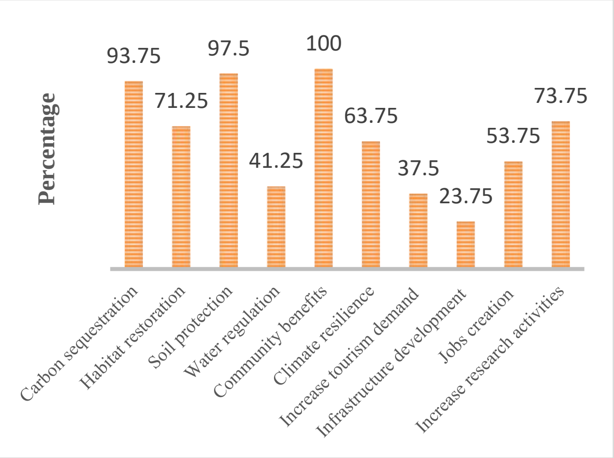


Figure 2. Social-economic impact of native tree species reforestation

CONCLUSIONS AND RECOMMENDATIONS:

The majority of the trees found in Rwanda belong to the exotic species. As the native tree species are the basis of the urban and natural landscape, further efforts should be made to encourage the planting of these native tree species to increase the proportion of these species in both urban and rural areas and promote sustainable biodiversity. The study indicated that the majority of the respondents were male with 57.5%. The findings of this study revealed the first class for native tree species threats was the firewood followed by animal grazing, medicine, building, others, and food respectively. The result of the regression analysis revealed age, gender, occupation, household size, price of fuel, tree product use, and distance to the forest influenced negatively native tree species threatening.

This study revealed that the most common social economic benefits of native tree species reforestation are community benefits, soil protection, carbon sequestration, increase research activities, habitat restoration, climate resilience, jobs creation, water regulation, increase tourism demand, and infrastructure development. If properly planned and implemented, native tree species can provide a host of environmental, economic, religious, and aesthetic benefits. From a purely aesthetic perspective, native plants are often more attractive, colourful, and fragrant than exotic plants.

Additionally, native tree species require less maintenance, are more tolerant of local conditions, and require fewer pesticides and fertilizers to thrive. Native tree species often require less water and can be used to create natural buffers that reduce noise and air pollution. Finally, from an economic perspective, native plants can improve property values, reduce energy costs, and create a more desirable living environment. Native tree species can also reduce the risk of invasive species, which might be costly and difficult to remove. Policymakers and planners should consider the importance of incorporating native tree species into their plans to ensure a more sustainable and resilient for both urban and rural natural environments.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Akindele, S.O. 2012. Status of forest cover in Nigeria. *Proceedings of the Third National Conference of the Forest and Forest Products Society. 3rd – 6th April, 2012*.

Akpan-ebe, Isidore Nelson. 2017. "Reforestation in Nigeria: History, current practice and future perspectives". *Reforesta*. 3 (3): 105–115.
doi:10.21750/REFOR.3.09.33. ISSN 2466-4367

Andrew David Almas; Tenley M. Conway 2017. Residential Knowledge of Native Tree Species: A Case Study of Residents in Four Southern Ontario Municipalities. University of British-Columbia.

Belete Limani Kerse. 2016. Factors Affecting Local People Participation in Forest Managed for Carbon Sequestration. The Case of Mount Damota, Southern Ethiopia. *Developing Country Studies*, **6**(5).

Charles, H., & Dukes, J. S. 2007. Impacts of invasive species on ecosystem services. *Biological invasions*, 217- 237.

Chhetri, K.B. 2005. Community Forestry Program in the Hills of Nepal: Determinants of User Participation and Household Dependency. Department of International Environment and Development Studies. Norwegian University of Life Sciences (UMB).

Chokkalingam, U., Carandang, A.P., Pulhin, J.M., Lasco, R.D., Peras, R.J.J., Toma, T., 2006a. One Century of Forest Rehabilitation in the Philippines: Approaches, Outcomes and Lessons. Country Case Studies on Review of Forest Rehabilitation Initiatives: Lessons from the Past. Center for International Forestry Research (CIFOR), Situ Gede, Sindang Barang Bogor Barat 16680, Indonesia.

CIFOR Rehab Team. 2006. Forest Rehabilitation e-Learning from the Past From. http://www.cifor.cgiar.org/Publications/Corporate/AnnualReports/English2006/rehabilitation.htm

Dudley, N., Mansourian, S., Vallauri, D. 2005. Forest landscape restoration in context. In: Mansourian, S., Vallauri, D., Dudley, N. (Eds.), Forest Restoration in Landscapes. Springer, New York, pp. 3-7.

Etuk, L.A; Collins, J.B. 1976. Suggested scheme for reforestation and cropping of abandoned farmlands in Nigeria. *Journal of Agro Economic Education*. **5**: 41–43. doi:10.2134/jae.1976.0041.

Faham, E., Rezvanfar, A. and Shamekhi, T. 2008. Analysis of socio-economic Factors influencing forest dwellers' participation in Reforestation and Development of Forest Areas (The case study of West Mazandran, Iran). *American Journal of Agricultural and Biological Sciences*.**3**(1): 438-443.

GoR. 2016. Green Economy Baseline Survey Report - Rwanda 2016

Hassan R. M. and Hertzler G. 1988. Deforestation from the overexploitation of wood resources as a cooking fuel: a dynamic approach to pricing energy resources in Sudan. *Energy Economics*, **10**(2): 163–168, 1988.

Ibimilua A. F. 2012. Appraisal of the causes and consequences of human induced deforestation in Ekiti State, Nigeria. *Journal of Sustainable Development in Africa*, **14**(3): 37–52.

Kühn, I., & Klotz, S. 2006. Urbanization and homogenization comparing the areas of urban and rural areas in Germany. *Biological Conservation*, **127**(3): 292-300.

Maginnis, S., Jackson, W. 2002. Restoring forest landscapes From. http://cmsdata.iucn.org/downloads/restoring_forest_landscapes.pdf (accessed 15.07.10).

MININFRA. 2008a. Biomass Strategic Workshop, 30th April 2008. Ministry of Infrastructure (MININFRA), Kigali.

MINITERE-ISAR. 2007. Rapport d'inventaire des ressources ligneuses au Rwanda. Volume 2, Ministère des Terres, de l'Environnement, des Forêts, de l'Eau et des Mines (MINITERE) and the National Agricultural Research Institute (ISAR), Kigali.

Montagnini, F. 2005. Selecting tree species for plantation. In: Forest Restoration in Landscapes: Beyond planting trees. Springer, New York, pp. 262-268.

Nawir, A.A., Murniati, Rumboko, L. 2007. Forest Rehabilitation in Indonesia: Where to after Three Decades? Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Nentwig, W., Bacher, S., Kumschick, S., Pyšek, P., & Vilà, M. 2018. More than "100 worst" alien species in Europe. *Biological Invasions*, **20**(6): 1611-1621.

Ngounou, Boris. 2021. NIGERIA: Kano State launches a one million tree reforestation campaign | Afrik 21. *Afrik 21*. Retrieved 17 September 2023

NISR. 2022. Fifth Rwanda Population and Housing Census, 2022 (NISR)

Park, Chris; Allaby, Michael 2017. "Afforestation". *A Dictionary of Environment and Conservation*. Oxford doi:10.1093/acref/9780191826320.001.0001

Ramakrishnan, P.S., Campbell, J., Demierre, L., Gyi, A., Malhotra, K.C., Mehndiratta, S., Rai, S.N., Sashidharan, E.M. 1994. Ecosystem Rehabilitation of the Rural Landscape in South and Central Asia: an Analysis of Issues. UNESCO, New Delhi.

REMA. 2015. Rwanda: State of Environment and Outlook Report 2015.

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Research Article

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Application of Multiple Criteria Decision-Making approach for ranking Lentil genotypes

Prit Mondal[1]*, Tufleuddin Biswas[1, 2], Prity Maji[1] and Anurup Majumder[1]
[1]*Department of Agricultural Statistics, Bidhan Chandra Krishi Viswavidyalaya, P.O. Krishi Viswavidyalaya, West Bengal, India*
[2]*Department of Agricultural Economics and Statistics, Centurion University of Technology and Management, Odisha, India*
**Corresponding author e-mail: prit2330@gmail.com*
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ABSTRACT
The conception of the multiple criteria decision-making (MCDM) approach was applied to lentil genotypes under study to rank their performances. The study was conducted in University Research Farm, BCKV, West Bengal, during 2020-2021 and 2021-2022. The identification of 16 cultivars was performed using the above approach based on 7 different growth and yield attributing parameters. The concept of entropy was employed to assign suitable weights to the recorded characters for their relative importance in the assessment and ranking process. Considering 7 parameters (criteria), the variety L1112-7 ranked first. While the variety L1112-16 ranked the last. It was also observed that this approach was very robust as it can accommodate many alternatives for comparison with multiple numbers of characters or Alternatives.
Keywords: MCDM, TOPSIS, Entropy, Lentil

INTRODUCTION

Lentil is one of the important pulse crops worldwide for its nutritional value, market demands, affordability, nitrogen fixation, and drought resistance ability (Shrestha et al., 2023). Selection of location and agro-climatic condition-oriented genotypes is crucial for achieving this job. Several genotypes are available in different agro-climatic conditions. Decision-making is crucial in such situations. Multiple criteria decision-making (MCDM) is a usual technique in agriculture and other industries. Filar et al. (2003) applied the MCDM method, namely, the Technique for order of preference by similarity to ideal solution (TOPSIS) for multiple indicators of environmental evaluation. It has long been practiced to produce intercrops of products such as pineapples, sweet corn, shallots, papaya, and so on, and to grow two or more crops of these varied plants concurrently and combined in the same field. There have been many approaches available for solving MCDM problems, as summarized by Hwang and Yoon in 1981, but some of the methods were criticized as being ad hoc, and others have been thought to be, to some extent, inappropriate in theoretical or empirical grounds, as indicated by Stewart in 1992. The TOPSIS method was used by Filar et al. (2003) for environmental assessment based on several indicators. However, in general, MCDM methods are highly effective in helping decision-making in various conditions. Recently, Biswas et al. (2024) reported a successful application of the TOPSIS method in an experiment on a rice-based wheat cropping system under conservation agriculture to rank the fifteen tillage-based alternatives. However, the Analytic hierarchic process (AHP) method derived the criteria weights.

The present research looked at the application of MCDM approaches to the agricultural field, such as ranking crop varieties based on their performance. The application of MCDM to the agricultural sector did not get much attention in the past; it should be useful in decision support systems. For many years, several authors have attempted to identify a group of varieties suitable for a specific zone by either using;

i) The ANOVA model for selecting the better performers for each character under study or

ii) Clustering the varieties using Euclidean distance matrix and dendrogram, simultaneously considering multiple characters under study.

It can be shown that no performance evaluation method considering all the characters by a single index has yet been used on a large scale. Therefore, developing a single index that represents the entire set of traits under consideration is required to evaluate overall varietal performance fully and easily. Typically, such an index can be constructed as a function of the entire collection of varietal characteristics. Statistical techniques can be utilized to assess a single integrated indicator with appropriate robustness features for scientific

judgment about the performance of various types. In the current study, the above-mentioned MCDM approach was used to evaluate 16 cultivars of lentil based on 7 growth and yield-attributing characters, including Primary branches per plant, Number of pods per plant, 100 seeds weight, Yield (Kg/ha), Days to 50% flowering, Days to maturity and Plant Height (cm).

MATERIALS AND METHODS

The experiment was conducted in Kalyani, West Bengal, India (220 56' N and 880 32' E) at the University Research Farm of the Bidhan Chandra Krishi Viswavidyalaya over the summer seasons of 2020–2021 and 2021–2022. The investigation was conducted using the average values for the aforementioned seasons. In the current study, the aforementioned MCDM approach has been used to assess sixteen cultivars of lentil on seven growth and yield-attributing traits: primary branches per plant, number of pods per plant, 100 seed weight, yield (kg/ha), days to 50% flowering, days to maturity and plant height (cm).

Database

Sixteen lentil cultivars were used for investigation. Each of the sixteen cultivars was noticed with the aforementioned seven characters. To make the cultivars easier to understand and for simplicity, let's use the abbreviations S1, S2,…and S16. We also focus on the seven characters for each variety, which are marked as C_1, C_2,… and C_7.

MCDM method

MCDM involves constructing and resolving multiple-criteria decision and planning problems. The goal is to assist decision-makers who are facing these issues. Assume K's total choices must be evaluated before choosing the best one. Assign the possibilities to the letters $S_1, S_2, ..., S_K$. N criteria are also identified to evaluate the options, represented by $C_1, C_2, ..., C_N$. The k^{th} alternative's value on the n^{th} criteria is derived as x_{kn}, and we write $S_k = (x_{k1}, x_{k2}, ..., x_{kN})$ and $Cn = (x_{1n}, x_{2n}, ..., x_{kn})$; k = 1,2,….,K and n = 1,2,…..,N.

The TOPSIS method and related topics

This method of compensatory aggregation examines a group of alternatives by determining weights for each criterion, normalizing scores for each criterion, and computing the geometric separation between each alternative and the ideal alternative (which is the alternate with the best score in each criterion) as well as negative ideal alternative (which is the alternate with the worst score in each criterion). TOPSIS presupposes that the criteria are monotonically rising or decreasing. Normalization is required when the factors are recorded with inconsistent dimensions and scales. Trade-offs between criteria are possible using compensatory approaches like TOPSIS, where a strong performance in one criterion can offset a weak performance in another. This gives a more realistic kind of modeling than non-compensatory techniques, which include or exclude alternate solutions based on strict cut-offs. TOPSIS's key principle is that the optimal option should be the closest to the ideal alternatives and far away from the negative ideal alternative, which is both intuitive and crucial.

The Ideal Solution

Define the positive ideal alternative (excessive performance on each criterion) and the negative ideal alternative (opposite extreme performance on each criterion). The ideal positive solution maximizes the benefit criterion while minimizing the cost criteria, whereas the negative ideal solution maximizes the cost criteria while minimizing the benefit criteria. The positive ideal $S^+ = (x^+_1, x^+_2, ..., x^+_N)$ and the negative ideal $S^- = (x^-_1, x^-_2, ..., x^-_N)$ is created by taking all the best values reached on each criterion by some alternatives and all the worst values attained on each criterion by some alternatives, respectively.

The TOPSIS procedure

With the aforementioned notation and explanation, the TOPSIS technique for evaluating the ranking of the K options based on their values on the N criteria may be expressed as follows;

The normalized form of the n^{th} criteria vector Cn is TCn. As a result, the k^{th} alternative vector S_k, the positive ideal solution S^+, and the negative ideal solution S^- are also changed to TS_k, TS^+, and TS^-, respectively.

Next, $d(S_k, S^+)$ is defined as the weighted Euclidean distance of TS_k from TS^+;

$d(S_k, S^+) = \| w \bullet (TS_k - TS^+)\|$, where ($\bullet$) is the vector product and w is the weight.

$=\sqrt{(\sum_{n=1}^{N}(Wn(t_{kn} - t_{+n}))^2)}$

Similarly,

$d(S_k, S^-)$ is defined as,

$d(S_k, S^-) = \sqrt{(\sum_{n=1}^{N}(Wn(t_{kn} - t_{-n}))^2)}$

The K alternatives are evaluated in order of performance by their proximity to the ideal solution S^+, which is given for the k^{th} alternatives;

$r(S_k, S^+) = d(S_k, S^+)/ [d(S_k, S^+) + d(S_k, S^-)]$.

TOPSIS's evaevaluation criteria are founded on the idea that the smaller the value of $r(S_k, S^+)$, the more preferable the option.

Choice of weights

The entropy concept has been used to determine the internal importance or weights. It is a criterion for the amount of information (or uncertainty) conveyed by a discrete probability distribution, $p_1, p_2, ..., p_k$. Shannon (1948) created this level of information as $E(p_1, p_2, \ldots, p_k) = -\phi_k \sum_{k=1}^{K} p_k \ln(p_k)$, where $\phi_k = 1/\ln(k)$ is a positive constant ranging from 0 to 1. Now assuming that $p_{kn} = x_{kn} / X_n$, where $X_n = x_{k1} + x_{k2} + \ldots + x_{kN}$ as the probability distribution of C_n on the K alternatives, we may similarly define the entropy of Cn as $E(Cn) = -\phi_k \sum_{k=1}^{K} p_k \ln(p_k) = -\phi_k \sum_{k=1}^{K}(xkn/Xn)\ln(xkn/Xn)$, n = 1,2,…, N and define the weights as $Wn = (1-E(Cn)) / \sum_{j=1}^{N}(1-E(Cj))$, n = 1,2,…,N. and k = 1,2,…..K.

RESULTS AND DISCUSSIONS

Table 1 shows the average values of various growth and yield contributing features. For each character, the maximum and lowest values are indicated using red and green, respectively. The hypothetical alternative genotype prepared from the recorded data is listed as S^+ in the last row of Table 3.1 with all maximum values. Similarly, the fictitious alternative genotype with all minimum values generated as S^- is listed in the last row of Table 1.

Table 1. Average Yield and yield attributing characters of lentil for the years 2020-21 and 2021- 22:

Genotypes	Primary branches per plant	Number of pods per plant	100 seeds weight	Yield (Kg/ha)	Days to 50% flowering	Days to maturity	Plant Height (cm)
L1112-6	4.3	146.7	1.57	1626.24	84	120.5	49.1
L1112-7	3.6	145.9	2.14	1907.08	84	118.5	48.09
L1112-8	2.7	87.2	3.01	1652.49	71	119	41.26
L1112-9	2.1	86.4	1.59	1375.83	87	118.5	34.13
L1112-10	2.8	84	2.09	872.91	47.5	93	34.5
L1112-11	2.6	55.6	1.6	802.08	53	106	32.25
L1112-12	3	98	2.31	1031.25	53.5	110	33.67
L1112-13	2.6	52.2	2.15	859.16	46	102.5	29.65
L1112-14	2.6	76.8	2.29	1430.83	63	110	36.76
L1112-15	2.3	74.9	2.01	1541.24	74.5	116	45.23
L1112-16	2.2	38.9	2.87	329.58	52.5	91	33.2
L1112-17	2.3	73.1	2.79	1301.25	68	116.5	35.3
L1112-18	3.6	68.1	2.06	842.91	45.5	92.5	33.89
L1112-19	2.9	90.8	2.65	1481.66	76	117	38.58
L1112-20	2.1	72.8	2.23	1370	81	116.5	45.07
Subrata	2.8	80.4	1.67	1852.08	75	111.5	43.75
*S^+	4.3	146.7	3.01	1907.08	87	120.5	49.1
*S^-	2.1	38.9	1.57	329.58	45.5	91	29.65
* S^+ and S^- are positive Ideal and Negative Ideal solutions							

Table 2 computed the square root of the sum of the squares of the various characters in Table 1. This table was used for deriving the normalized values for each genotype shown in Table 1.

Table 2. Square root of the sum of square of different characters of Table 3.1:

[C_1]	[C_2]	[C_3]	[C_4]	[C_5]	[C_6]	[C_7]
11.371	351.232	8.936	5343.188	271.472	441.493	155.440

Table 3 presents the normalized values for each studied criterion-.

Table 3. Transformed Table with normalized values of Table 1:

Transformed Genotypes	TC_1	TC_2	TC_3	TC_4	TC_5	TC_6	TC_7
TS_1	0.3781	0.4177	0.1757	0.3044	0.3094	0.2729	0.3159
TS_2	0.3166	0.4154	0.2395	0.3569	0.3094	0.2684	0.3094
TS_3	0.2374	0.2483	0.3368	0.3093	0.2615	0.2695	0.2654
TS_4	0.1847	0.2460	0.1779	0.2575	0.3205	0.2684	0.2196
TS_5	0.2462	0.2392	0.2339	0.1634	0.1750	0.2106	0.2220
TS_6	0.2286	0.1583	0.1791	0.1501	0.1952	0.2401	0.2075
TS_7	0.2638	0.2790	0.2585	0.1930	0.1971	0.2492	0.2166
TS_8	0.2286	0.1486	0.2406	0.1608	0.1694	0.2322	0.1907
TS_9	0.2286	0.2187	0.2563	0.2678	0.2321	0.2492	0.2365
TS_{10}	0.2023	0.2132	0.2249	0.2884	0.2744	0.2627	0.2910
TS_{11}	0.1935	0.1108	0.3212	0.0617	0.1934	0.2061	0.2136
TS_{12}	0.2023	0.2081	0.3122	0.2435	0.2505	0.2639	0.2271
TS_{13}	0.3166	0.1939	0.2305	0.1578	0.1676	0.2095	0.2180
TS_{14}	0.2550	0.2585	0.2966	0.2773	0.2800	0.2650	0.2482
TS_{15}	0.1847	0.2073	0.2496	0.2564	0.2984	0.2639	0.2900
TS_{16}	0.2462	0.2289	0.1869	0.3466	0.2763	0.2526	0.2815

*TS^+	0.3781	0.4177	0.3368	0.3569	0.3205	0.2729	0.3159
*TS^-	0.1847	0.1108	0.1757	0.0617	0.1676	0.2061	0.1907
* TS^+ and TS^- are positive Ideal and Negative Ideal solutions. The values of the cells in table 3.3 are $C_{ij}/[C_i]$, where i = 1, 2, 3,..., 7 and j = 1, 2, 3,..., 16. The cell values in Table 3.3 are now scale-free.							

Then the sum for each column of Table 1 will be prepared in Table 4.

Table 4. Sum of each column of Table 3.1:

Column sum of table no. 1	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Sum	44.50	1331.80	35.03	20276.59	1061.50	1759.00	614.43

These numbers will be used to create Table 5 with the probability values for each cell in Table 1.

Table 5. Probability matrix of Table 1:

P-Matrix	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S_1	0.0966	0.1102	0.0448	0.0802	0.0791	0.0685	0.0799
S_2	0.0809	0.1096	0.0611	0.0941	0.0791	0.0674	0.0783
S_3	0.0607	0.0655	0.0859	0.0815	0.0669	0.0677	0.0672
S_4	0.0472	0.0649	0.0454	0.0679	0.0820	0.0674	0.0555
S_5	0.0629	0.0631	0.0597	0.0431	0.0447	0.0529	0.0561
S_6	0.0584	0.0417	0.0457	0.0396	0.0499	0.0603	0.0525
S_7	0.0674	0.0736	0.0659	0.0509	0.0504	0.0625	0.0548
S_8	0.0584	0.0392	0.0614	0.0424	0.0433	0.0583	0.0483
S_9	0.0584	0.0577	0.0654	0.0706	0.0593	0.0625	0.0598
S_{10}	0.0517	0.0562	0.0574	0.0760	0.0702	0.0659	0.0736
S_{11}	0.0494	0.0292	0.0819	0.0163	0.0495	0.0517	0.0540
S_{12}	0.0517	0.0549	0.0796	0.0642	0.0641	0.0662	0.0575
S_{13}	0.0809	0.0511	0.0588	0.0416	0.0429	0.0526	0.0552
S_{14}	0.0652	0.0682	0.0756	0.0731	0.0716	0.0665	0.0628
S_{15}	0.0472	0.0547	0.0637	0.0676	0.0763	0.0662	0.0734
S_{16}	0.0629	0.0604	0.0477	0.0913	0.0707	0.0634	0.0712

To find out the relative weights, we have to calculate the following value (ϕ).

Φ = 1/ ln (number of alternatives= 16); ln indicates log base 10 value.

ϕ =	0.3607

Table 6. Table for $E(C_i)$:

$E(C_i)$	$E(C_1)$=	$E(C_2)$=	$E(C_3)$=	$E(C_4)$=	$E(C_5)$=	$E(C_6)$=	$E(C_7)$=
Values	0.9924	0.9808	0.9926	0.9776	0.9914	0.9985	0.9957

Table 6 is prepared for the entropy value of characters. The values are estimated by
following the formula given as,

$E(Cn) = -\ \phi_k \sum_{k=1}^{K} p_k \ln(p_k) = -\ \phi_k \sum_{k=1}^{K} (xkn/Xn) \ln(xkn/Xn)$, n = 1,2,…, N and define the weights as $Wn = (1- E(Cn)) / \sum_{j=1}^{N}(1 - E(Cj))$, n = 1,2,…,N. and k = 1,2,…..K.

Next prepare the Table 7 as 1- E(Ci)

Table 7. Table for 1 - $E(C_i)$:

1-$E(C_1)$	1-$E(C_2)$	1-$E(C_3)$	1-$E(C_4)$	1-$E(C_5)$	1-$E(C_6)$	1-$E(C_7)$	SUM
0.0076	0.0192	0.0074	0.0224	0.0086	0.0015	0.0043	0.0709

The weights of each character under consideration are estimated using the tables (Tables 6 and 7). It's possible that not all of the characters being studied are equally significant, and the scale values may also have an impact on the study's eventual goal. Giving relative weight to the characters being studied is therefore a crucial component of decision-making studies in order to overcome these challenges.

Table 8. Table of weights using entropy:

Characters	W_1	W_2	W_3	W_4	W_5	W_6	W_7
Weight values	0.1076	0.2703	0.1043	0.3162	0.1208	0.0208	0.0600

The choice of weights is not original. The experimenter may select various weightage values according to the relative importance of the character. We may now move on to the study's last phase, which involves ranking each of the sixteen genotypes or cultivars of lentils being examined.

The Weighted Euclidean Distance from the ideal solution $d(S_k, S^+)$ is first calculated using the formula

$$d(S_k, S^+) = \sqrt{(\sum_{n=1}^{N}(Wn(t_{kn} - t_{+n}))^2)}$$

Similarly,

$$d(S_k, S^-) = \sqrt{\left(\sum_{n=1}^{N}(Wn(t_{kn} - t_{-n}))^2\right)}$$

The K alternatives are ranked according to how closely they adhere to the ideal solution S^+, which is provided for the k^{th} option, using the formula

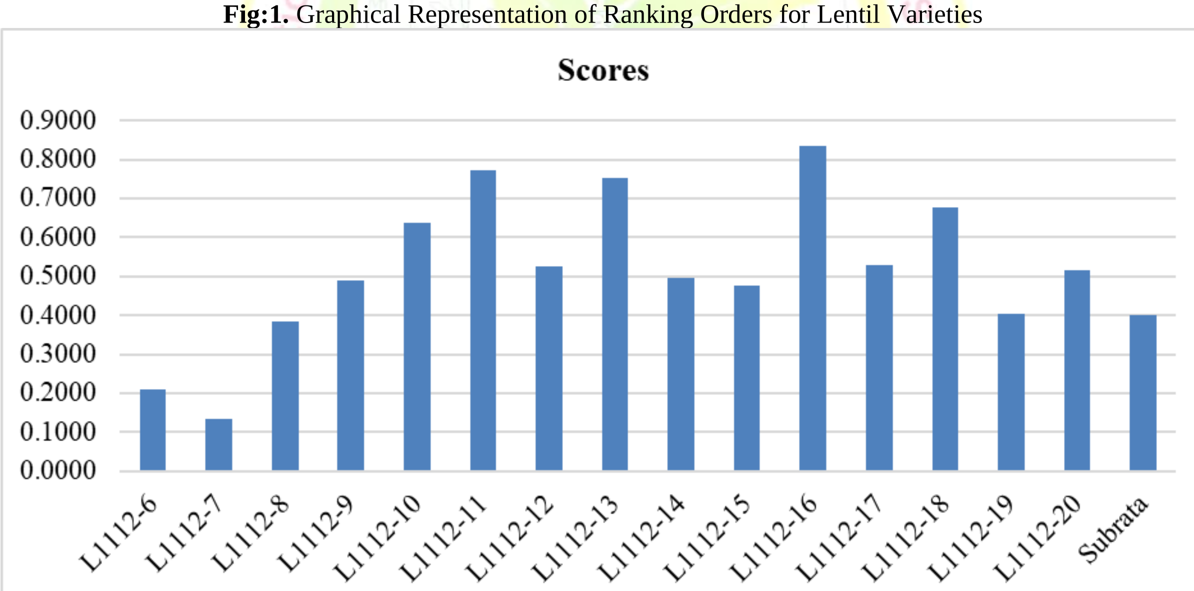
$$r(S_k, S^+) = d(S_k, S^+) / [d(S_k, S^+) + d(S_k, S^-)].$$

According to TOPSIS's evaluation criterion, the greater the favoured option is, the smaller the value of $r(S_k, S^+)$ must be.

Table 9. Ranking of Genotypes or cultivars of lentil

Genotypes /Cultivars	S_k	Distance from Ideal	Value	Distance from negative Ideal	Value	$r(S_k, S^+)$	Scores	Rank
L1112-6	S_1	$D(S_1,S^+)$	0.0600	$D(S_1,S^-)$	0.2271	$R(S_1,S^+)$	0.2089	2
L1112-7	S_2	$D(S_2,S^+)$	0.0376	$D(S_2,S^-)$	0.2415	$R(S_2,S^+)$	0.1348	1
L1112-8	S_3	$D(S_3,S^+)$	0.1057	$D(S_3,S^-)$	0.1703	$R(S_3,S^+)$	0.3831	3
L1112-9	S_4	$D(S_4,S^+)$	0.1353	$D(S_4,S^-)$	0.1415	$R(S_4,S^+)$	0.4888	7
L1112-10	S_5	$D(S_5,S^+)$	0.1631	$D(S_5,S^-)$	0.0925	$R(S_5,S^+)$	0.6382	12
L1112-11	S_6	$D(S_6,S^+)$	0.1983	$D(S_6,S^-)$	0.0585	$R(S_6,S^+)$	0.7721	15
L1112-12	S_7	$D(S_7,S^+)$	0.1348	$D(S_7,S^-)$	0.1212	$R(S_7,S^+)$	0.5267	10
L1112-13	S_8	$D(S_8,S^+)$	0.1970	$D(S_8,S^-)$	0.0645	$R(S_8,S^+)$	0.7535	14
L1112-14	S_9	$D(S_9,S^+)$	0.1328	$D(S_9,S^-)$	0.1347	$R(S_9,S^+)$	0.4965	8
L1112-15	S_{10}	$D(S_{10},S^+)$	0.1331	$D(S_{10},S^-)$	0.1464	$R(S_{10},S^+)$	0.4761	6
L1112-16	S_{11}	$D(S_{11},S^+)$	0.2437	$D(S_{11},S^-)$	0.0482	$R(S_{11},S^+)$	0.8348	16
L1112-17	S_{12}	$D(S_{12},S^+)$	0.1428	$D(S_{12},S^-)$	0.1264	$R(S_{12},S^+)$	0.5305	11
L1112-18	S_{13}	$D(S_{13},S^+)$	0.1765	$D(S_{13},S^-)$	0.0838	$R(S_{13},S^+)$	0.6781	13
L1112-19	S_{14}	$D(S_{14},S^+)$	0.1055	$D(S_{14},S^-)$	0.1564	$R(S_{14},S^+)$	0.4028	5
L1112-20	S_{15}	$D(S_{15},S^+)$	0.1417	$D(S_{15},S^-)$	0.1334	$R(S_{15},S^+)$	0.5151	9
Subrata	S_{16}	$D(S_{16},S^+)$	0.1191	$D(S_{16},S^-)$	0.1784	$R(S_{16},S^+)$	0.4004	4

Fig:1. Graphical Representation of Ranking Orders for Lentil Varieties



CONCLUSIONS

The study established that the genotype L1112- 7 (S_2) has the smallest $r(S_k, S^+)$ score meaning that it is the shortest distance away from the positive ideal genotype while also being the furthest distance away from the genotype of the negative ideal solution followed by L1112-6. As a result, L1112- 7 was the highest-ranking genotype when all seven characters were combined. Contrastingly, the genotype L1112- 16 (S_{11}) has the highest $r(S_k, S^+)$ score, indicating the furthest distance from the positive ideal option and the closest to the genotype of the negative ideal, the lowest ranking genotype when all seven traits were considered together. Our study established the application of the TOPSIS method in ranking agriculture alternative (s). However, including more conflicting criteria from diverse agriculture departments, for example, economics, crop protection, and energy criteria (i.e., fertilizers application, fuel, labor, machinery used, etc.), would give a better precision of the genotype ranking.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

AUTHOR'S CONTRIBUTION

P.M (Principal author): employed the methodology, collected data and analysed the data; A.M: supervised the overall study and drafted the MS; P.M: collected and arranged the data and T.B: reviewed and edited the MS. All the authors read and approved the final version of the MS.

REFERENCES

Biswas, T., Majumder, A., Dey, S., Mandal, A., Ray, S., Kapoor, P., Emam, W., Kanthal, S., Ishizaka, A. and Matuka, A. 2024. Evaluation of management practices in rice–wheat cropping system using multicriteria decision-making methods in conservation agriculture. *Scientific Reports*, **14**(1): 8600

Filar, J.A., Ross, N.P. and Wu, M.L. 2003. Environmental assessment based on multiple indicators. *Cal.Statist. Assoc. Bull*. **54** (March-June), 93-99.

Sahu, A., Nath, R., Mukhopadhyay, S. K., Majumder A., and Sounda, G. 2009. Ranking of Short Duration, Bold Seeded Groundnut Cultivars Based on Performance by MCDM Approach. *Indian Agriculturist*. **53**(3/4):189-192.

Shannon, C. E. 1948. A Mathematical Theory of Communication. The Bell System Technical Journal, **27:** 379 – 423.

Shrestha, S., van't Hag, L., Haritos, V.S. and Dhital, S. 2023. Lentil and Mungbean protein isolates: Processing, functional properties, and potential food applications. *Food hydrocolloids*, **135**: 108142

Stewart, TJ. 1992. A Critical Survey on the Status of Multiple Criteria Decision-Making Theory and Practice. OMEGA *Int. J. of Mgrnt Sci*., **20**(5/6): 569-586.

Yoon K, Hwang, C.L. 1995. Multiple Attribute Decision Making: An Introduction. Sage Publications.

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Research Article

OPEN ACCESS

Unlocking the Green Potential: Enhancing Maize (*Zea mays* L.) Germination, Growth, and Yield through Innovative Seed Priming in Taplejung, Nepal

Prashna Budhathoki[1]*, Shreejan Kumar Pandey[1], Shiva Shankar Bhattarai[1] and Prakash Ghimire[2]
[1]Mahendra Ratna Multiple Campus, Institute of Agriculture and Animal Science, Ilam, Nepal
[2]Paklihawa Campus, Institute of Agriculture and Animal Science, Nepal
**Corresponding author e-mail: prashnabudhathoki2@gmail.com*
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ABSTRACT

A cheap and ecologically friendly pre-sowing method that increases germination rates and seedling vigor, which in turn enhances growth and productivity, is considered seed priming. A field experiment was conducted in 2022 in farmer's field to evaluate the effective priming method suitable for the balanced germination, growth, and yield of maize. An experiment consists of a single-factor randomized complete block design with 3 replications and 8 treatments. The analysis of the data was conducted with R Studio software at the $p < 0.05$ level of significance, and a mean comparison was done using DMRT (Duncan's Multiple Range Test). According to this study, seed priming increased the germination, growth, and yield of crop growth parameters such as germination percentage, germination index, days to 100% germination, stem diameter at 35 days, days to 100% tasseling, days to 100% silking, plant population/ha, number of cobs per plant, ear length, ear girth, kernels per cob, 1000 kernel weight, fresh grain yield, adjusted grain yield, fresh Stover yield, and fresh biomass yield. The highest germination percentage (98.61%) and index (11.89 days), the earliest days to 100% germination (12.00 days), early tassel emergence (63.00 days), early silking emergence (66.00 days), the highest number of kernels per cob (529.37), 1000 kernel weight (337.10 g), harvest index (0.62), ear length (22.38 mm), and ear girth (49.72mm) were recorded on the treatment primed with cow urine for 18 hours. However, the highest fresh Stover yield (2954.07 kg/ha) and fresh biomass yield (6336.29 kg/ha) are recorded on stoves primed with DAP for 18 hours. Cow-urine priming for 18 hours improved the germination and economic yield of maize. Efficient cow-urine priming is a cost-effective, eco-friendly, and finest alternative approach to increasing the maize yield.
Keywords: Hydro-Priming, Cow urine Priming, Effect, Germination, growth, yield.

INTRODUCTION

Maize is a significant agronomic crop that is cultivated globally and is cross-pollinated long-day plant belonging to Poaceae. Maize is referred as the "queen of cereals." It is used for food, feed, fodder, and a source of industrial raw materials in Nepal, where it is recognized as the second most important cereal crop after rice (Ghimire, et al., 2018). Per capita, maize consumption in Nepal was 98g per person in one day which was reported to be the highest in South Asia (Ranum, et al., 2014). The demand for maize has been steadily increasing by about 5% annually in the past few decades (Sapkota & Pokhrel, 2010). Currently, maize covers 9,56,447 ha of land with a total yield of 2,71,3635 in Nepal (Krishi Diary, 2078) whereas in Taplejung district maize is cultivated in 22,052ha of land, 54,413Mt production and yield of 2.47Mt/ha were recorded (MOAD, 2014). In the winter and spring, maize is farmed in the terai, valleys, and low-lying river basin areas using irrigation whereas during the summer (April-August), maize is grown under the rainfed condition as sole crop or relayed with millet at the end of season (Sapkota & Pokhrel, 2010). The potential yield of maize in Nepal is 5.7 t/ha, which is higher than the farm-level production of 2.55 t/ha (MOAD, 2017; Karki et al., 2015). In Nepal, maize being impacted by various technological and socio-economic factors, there is an enormous gap between the demand and production. It is mostly unknown in Nepalese context how the pretreated seed would affect the entire growing season. Seed is considered as primary component that has an impact on crop's production and productivity (Shrestha & Shrestha, 2017).

Seed priming is considered a low-cost and eco-friendly pre-sowing technique that can improve the germination rate and vigor of seedlings which reflects enhanced crop growth and productivity. (Sudozai, et al., 2013) found maize seeds hydro-primed for 18 hours at a soil moisture level of 55-65% enhances germination characters like vigor index, greatest emergence and increase in growth

parameters like greatest leaf area, shoot as well as root dry weights. Additionally, it also promotes yield parameters like greatest number of cobs per plant, grains per cob and improved seed index along with increasement in seed yield by 35%. Maize is one of the important cereal crops of Bangladesh which can be produced successfully by priming (Ahammad, et al., 2014).

Furthermore, research conducted by (Soleimanzadeh, 2013) hydro-primed maize seeds for duration of 18 hours enhances seed germination and yield factors. Koirala (2017) reported seed priming treatment reduces silking and maturity days, enhancing increasement of grain yield by 11.6% and greatest increasement of yield by 27.8% in maize (Manakamana-1 variety) at Palpa, Gulmi, and Myagdi districts of Nepal. The significant numbers of farmers (75.1 to 88.9%) who took part in the Mother-Baby trial in western Nepal expressed keen interest in seed priming technology in maize (Koirala, 2017). For solving the issue of low seedling establishment problem, farmers require priming reagents that are not only affordable but also user-friendly and readily available in Nepal. Hence, this experiment was undertaken in the farmers' field in Mid hills of Nepal with the motive of identification of priming treatments in seed germination, better establishment, vegetative growth, and Yield of maize in Mid hills of Nepal. If Germination, growth, and yield performance are unaffected by the use of different treatments, it will be considered as a null hypothesis.

Experimental site

From February 2022 to June 2022, the experiment was carried out in a farmer's field in Phungling municipality-04, Simle, Taplejung. The site is situated at an elevation of 1140 meters above sea level, with coordinates of 27.3487973 N, 87.6398160 E..

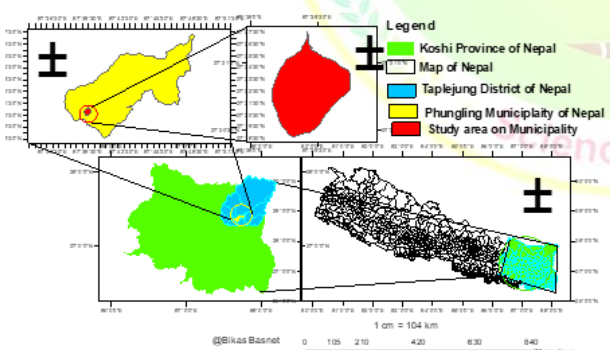

Figure 1. Geographic Information System (GIS) Map of the Study Area in Taplejung, Nepal. This study marks the inaugural investigation conducted in this specific location. Map created by the author

Experimental design

The experiment was set up in a single factor Randomized complete block design involving 3 replications and 8 different treatments. Maize (var. Manakamana-04) seed was obtained from Prime Minister Agriculture Modernization Project, Taplejung, and was placed in a bowl and soaked in water (Hydropriming (12 hours)-T1 & Hydropriming (18 hours)-T2), cow urine(Cow- Urine priming (12 hours)- T3, @ 2.5 times dilution & Cow-Urine priming (18 hours) @ 2.5 times dilution-T4), DAP(DAP priming (12 hours) @1%-T5 & DAP priming (18 hours) @1%-T6), and the salt solution(Salt priming (12 hours) @0.5%-T7) and Control-T8 respectively. Then the primed seed was surface dried under the shade for 2 hours.

In an area of 155m^2 of a well-prepared plot, seeds were shown at a depth of 5-8 cm. The distance between rows and plants of the maize was 75cm×25cm. Every replication had 1 m gap, and each plot had 0.5 m gap. Altogether there were 24 plots with an Individual plot area 2m×2.25m (4.5m2), each plot had 3 rows with 8 plants in each row (*Figure 2*). Six of the plants were chosen at random from each plot by a lottery procedure to provide the necessary data for the experiment. The experimental field was well-ploughed, weeds were cleared from the field and was given a fine tilth. After, the field layout was completed, the recommended doses of well-decomposed FYM (15 tons), Urea: DAP: MOP@120:60: 40 kg/ha were applied. FYM, DAP, MOP, and half dose of urea were applied as basal dose. While, half dose of urea was top-dressed during crucial stages i.e. knee-high stage and earthing up.

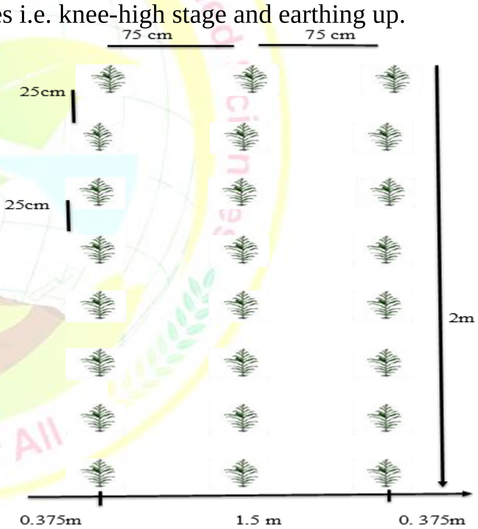

Figure 2. Experimental design of the Single Plot with the spacing of 75*25cm^2

Data collection and analysis

Six plants were randomly chosen as sample plants from each plot. Each plot included data collected on seedling character, Vegetative character, phenological observations, and yield attributing measurements. Seedling characters included seed germination percentage, germination index, and Days to 100% germination. Vegetative characters included Plant height (cm), Stem diameter (mm), and Number of leaves. Days to 100% Tasseling, Days to 100% silking were recorded as phenological observation. Yield attributing characters included Plant population per hectare, Number of cobs per plant, ear length(cm), ear girth(mm), kernels per cob,

1000 kernel weight(gm), Fresh Stover yield(gm), Fresh Biomass yield(gm), Harvest index. At a 5% level of significance, the data were examined using Duncan's Multiple Range Test (DMRT) and information gathered from field was put into MS-Excel 2019. The data were further analyzed with R studio version 4.2.1.

Seed germination percentage

The seedlings were observed daily until complete emergence and readings were taken.

$$\% \text{ Germination} = \frac{Number\ of\ seeds\ germinated}{Number\ of\ seeds\ sown} \times 100$$

Germination index

The germination index (GI) was calculated by the following formula:

$$\frac{Number\ of\ germinated\ seeds}{Days\ of\ first\ count} + \cdots + \frac{Number\ of\ germinated\ seeds}{Days\ of\ final\ count}$$

Days to 100% germination

Days to full germination were calculated when nearly 100% of the germination of seeds took place.

Plant height

Plant height were measured by using measuring tape from the randomly selected 6 plants from the middle row of each plot. Plant height were measured from the soil surface to the highest point of the arch of the uppermost leaf whose tip was pointing down.

Stem diameter

Stem diameter were measured through Vernier caliper from the randomly selected 6 plants from the middle row of each plot.

Number of leaves

Emerged number of leaves were counted from the randomly selected plants

Days to 100% tasseling and silking

After the emergence of 100% tassel in the plot, this data was recorded.

Plant population per hectare

Plant population per hectare was calculated by using the formula:

$$\frac{Total\ number\ of\ plants\ in\ given\ area\ of\ the\ plot\,(3m^2)}{Total\ area\ of\ the\ plot\ (3m^2)} \times 10000$$

Yield parameters

The total number of ears harvested from the net harvestable area were recorded. The length of the ear was measured from the base to the tip of the ear and were recorded in centimeters at the time of harvest. Ear girth was measured i.e., from the middle of the ears using a Vernier caliper, and was recorded in millimeters. Fresh cob weight along with husk was harvested from the net harvestable area and weighed using a weighing machine. De-husking of the cob was performed and was weighted using a weighing machine. Kernel per row, Kernel per column of the sample plant cob was calculated and was multiplied for calculation of kernels per cob

So,

(Number of Kernels per cob= kernel per row × kernel per column).

10000 kernels were counted and weighed in a weighing machine for calculation of 1000 grain weight. For Stover weight, Stover was cut down from the net harvestable area and was weighted using a weighing machine and converted in kg/ha Biological yield was calculated using the formula (Biological yield= Grain yield + Stover yield)

The Harvest index was calculated using the formula:

$$(\text{HI} = \frac{\text{Economic yield(Grain yield)}}{\text{Biological yield (Grain yield+Stover yield)}}).$$

Grain moisture content (%): Ears from random plants were selected. Kernels were shelled out and was placed in a moisture meter for calculating moisture content.

RESULTS AND DISCUSSIONS

Germination percentage

The data analysis performed showed that there was significant effect ($p<0.05$) of priming in germination percentage (Table 1). In comparison to other treatments, T4 primed with cow urine for 18 hours had the greatest germination rate (98.61) whereas T8 no priming, had the lowest recorded germination percentage (73.61).

Germination index

The data analysis performed showed that there was significant effect ($p<0.05$) of priming in Germination index (Table **1**) & *Figure* **3**. In comparison to other treatments, T4 primed with cow urine for 18 hours had the greatest germination rate (11.89) whereas T8 no priming was performed had the lowest germination index (4.22).

Days to 100% germination

The data analysis performed showed that there was significant effect ($p<0.05$) of priming in Days to 100% germination. In comparison to other treatments, T4 primed with cow urine for 18 hours had the greatest days to 100% germination (12.00) whereas T8, no priming performed had the lowest (13.00) (Table **1**) & *Figure* **3**.

Table 1. Effect of priming on germination parameter of Manakamana-4 variety of maize

Treatment	Germination percentage	Germination Index	Days to 100% germination
T1	93.06^{c}	9.06^{bc}	12.67^{ab}
T2	94.30^{b}	10.21^{b}	12.67^{ab}
T3	89.06^{c}	7.11^{c}	12.67^{ab}
T4	98.61^{a}	11.89^{a}	12.00^{b}
T5	84.72^{d}	5.60^{c}	13.00^{a}
T6	82.56^{d}	5.50^{c}	13.00^{a}
T7	90.06^{bc}	9.01^{bc}	13.00^{a}
T8	73.61^{e}	4.22^{d}	13.00^{a}
LSD (0.05)	3.58	1.21	0.40
S. E_m (±)	2.17	0.46	0.20
F-probability	<0.001	<0.001	<0.05
CV%	4.22	8.66	2.772968
Grand Mean	88.24	7.82	12.75

Note: The common letter(s) within the column indicate non-significant difference based on Duncan Multiple Range Test (DMRT) at 0.05 level of significance, ** significant at 1% level of significance, *** significant at 0.1% level of significance. (S. Em – Standard Error of mean, CV – Coefficient of Variation, LSD – Least Significance Difference)

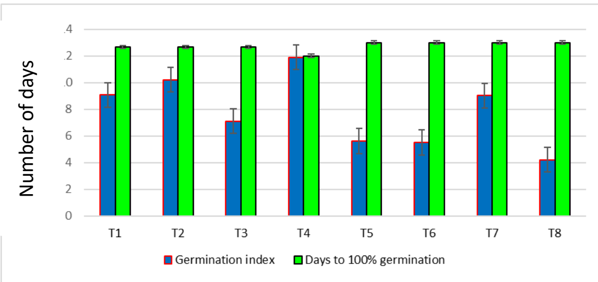

Figure 3. Effect of priming on germination index and days to 100% germination

Plant height

The analyzed data revealed that the plant heights 35, 50, 65, 80, and 105 days is not significantly ($p<0.05$) influenced (*Figure 4*).

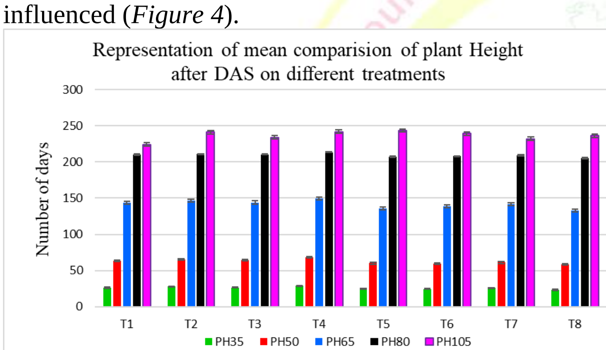

Figure 4. Effect of priming on plant height on different days after sowing

Leaves number

The analyzed data revealed that the Leaf number 35, 50, 65, 80, and 105 days is statistically not significantly ($p<0.05$) influenced (Figure 5).

Stem diameter

The analyzed data revealed that the stem diameter 35, 50, 65, 80, and 105 days is not significantly ($p<0.05$) influenced by the treatments (Figure 6).

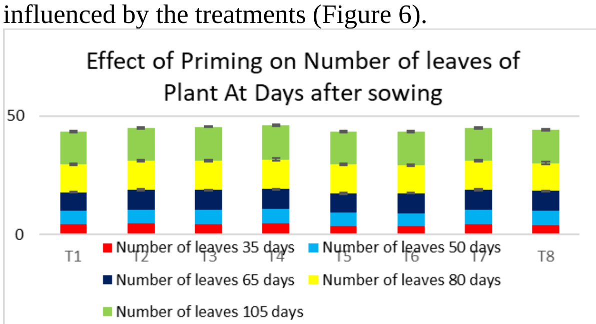

Figure 5. Effect of Seed priming on the number of leaves on different days of sowing

Days to 100% tasseling

The analyzed data revealed that the days to tasseling are significantly ($p<0.05$) influenced. However, the early tassel emergence was recorded in treatment T4, primed with cow-urine for 18 hours (63.00), and the late tassel emergence was recorded in T8, control no priming performed (69.67).

Days to 100% silking

The analyzed data revealed that the days to silking are significantly ($p<0.05$) influenced. However, the early silking emergence was recorded in treatment T4, primed with cow-urine for 18 hours (66.00) and the late tassel emergence was recorded in T8, with control no priming performed (72.66) (Table 2).

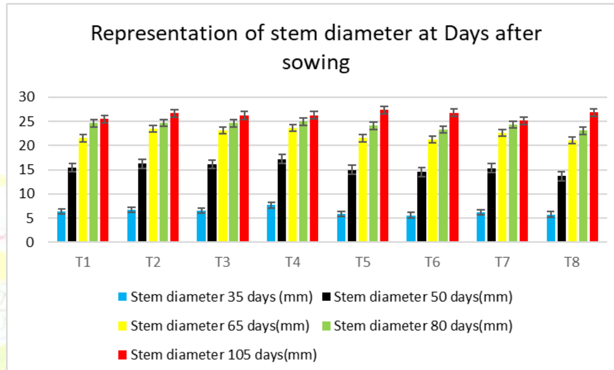

Figure 6. Effect of Seed priming on Stem diameter of maize at different days of sowing

Table 2. Effect of seed priming on days to tasseling, days to silking of maize

Treatment	Days to 100% tasseling	Days to 100% silking
T1	64.67^{ab}	68.33^{ab}
T2	64.67^{ab}	68.00^{ab}
T3	64.67^{ab}	68.00^{ab}
T4	63.00^{c}	66.00^{c}
T5	68.00^{b}	70.66^{b}
T6	68.67^{b}	71.66^{b}
T7	67.00^{b}	70.66^{b}
T8	69.67^{a}	72.66^{a}
LSD (0.05)	0.82	1.05
S. Em (±)	0.27	0.34
F-probability	<0.001	<0.001
CV%	0.70	0.86
Grand Mean	66.29	69.49

Note: The common letter(s) within the column indicate non-significant difference based on Duncan Multiple Range Test (DMRT) at 0.05 level of significance, ** significant at 1% level of significance, *** significant at 0.1% level of significance. (S. Em – Standard Error of mean, CV – Coefficient of Variation, LSD – Least Significance Difference)

Plant population per hectare

The analyzed data revealed that the plant population per hectare is significantly ($p<0.05$) influenced (Table 3). However, the highest plant population per hectare was recorded on the treatment T4, primed with cow-urine for 18 hours (75555.56), and the lowest plant population per hectare was recorded in T8, control no priming performed (53333.33) but statistically similar (at par) with T5, T6.

Number of cobs per plant

The analyzed data revealed that the number of cobs per plant is significantly ($p<0.05$) influenced (Table 3). However, the highest number of cobs per plant was recorded on the treatment T3, primed with cow-urine for 12 hours (2.01) and the lowest number of cobs per plant was recorded in T8, with control no priming performed (1.00).

Ear length

The analyzed data revealed that the ear length is significantly ($p<0.05$) influenced. However, the highest ear length was recorded in treatment T4, primed with cow-urine for 18 hours (22.38) and the lowest ear length was recorded in T8, with control no priming performed (16.85).

Ear girth

The analyzed data revealed that the ear girth is significantly ($p<0.05$) influenced. However, the highest ear girth was recorded in treatment T4, primed with cow-urine for 18 hours (49.72) and the lowest ear girth was recorded in T8, control no priming performed (42.44) (*Table 3*).

Table 3. Effect of seed priming on plant population per hectare, number of cobs per plant, ear length, ear girth

Treatment	Plant population per hectare	Number of cobs per plant	Ear length (cm)	Ear girth (mm)
T1	65777.78^{bc}	2.00^{ab}	18.15^{c}	46.61^{b}
T2	70057.00^{b}	1.42^{b}	19.65^{bc}	49.34^{a}
T3	69777.78^{b}	2.01^{a}	20.74^{b}	46.28^{ab}
T4	75555.56^{a}	1.68^{b}	22.38^{a}	49.72^{a}
T5	55555.56^{d}	1.05^{c}	17.05^{cd}	43.44^{c}
T6	55555.56^{d}	1.05^{c}	17.02^{cd}	43.02^{c}
T7	66888.89^{bc}	1.21^{bc}	18.04^{c}	45.67^{b}
T8	53333.33^{e}	1.00^{c}	16.85^{d}	42.44^{d}
LSD (0.05)	4000.55	0.18	1.42	2.46
S. Em (±)	1599.16	0.06	0.81	1.14
F-probability	<0.001	<0.05	<0.05	<0.05
CV%	4.30	9.21	7.16	4.30
Grand mean	64062.68	1.42	18.73	45.81

Note: The common letter(s) within the column indicate non-significant difference based on Duncan Multiple Range Test (DMRT) at 0.05 level of significance, ** significant at 1% level of significance, *** significant at 0.1% level of significance. (S. Em- Standard Error of mean, CV – Coefficient of Variation, LSD – Least Significance Difference)

Fresh cob weight

The analyzed data revealed that the fresh cob weight with husk is not significantly($p<0.05$) influenced. fresh cob weight without husk is not significantly ($p<0.05$) influenced Table 4

Number of Kernels per cob

The analyzed data revealed that the number of kernels per cob is significantly ($p<0.05$) influenced. However, the highest kernels per cob were recorded on treatment T4, primed with cow-urine for 18 hours (529.37), and the lowest kernels per cob were recorded in T8, with control no priming performed (376.00).

1000 kernel weight

The analyzed data revealed that the 1000 kernel weight is significantly ($p<0.05$) influenced (Table 4). However, the highest fresh 1000 kernel weight was recorded on the treatment T4, primed with cow-urine for 18 hours (337.10), and the lowest fresh 1000 kernel weight was recorded in T8, with control no priming performed (306.00) (*Table 4*).

Table 4. Effect of seed priming on fresh cob weight with husk, fresh cob weight without husk, kernels per cob, 1000 kernel weight

Treatment	Fresh cob weight with husk (gm)	Fresh cob weight without husk (gm)	Number of Kernels per cob	1000 kernel weight (gm)
T1	357.50	294.20	436.03^{bc}	324.30^{b}
T2	385.60	321.70	474.93^{ab}	334.00^{a}
T3	365.00	297.80	469.37^{ab}	335.00^{a}
T4	395.90	337.10	529.37^{a}	337.10^{a}
T5	370.00	285.60	417.02^{bc}	320.70^{bc}
T6	364.20	285.60	393.55^{c}	314.30^{c}
T7	348.30	293.60	442.02^{bc}	322.80^{bc}
T8	317.10	265.90	376.00^{c}	306.00^{d}
LSD (0.05)	59.90	49.43	63.68	8.30
S. Em (±)	19.75	16.29	20.99	2.73
F-probability	ns	ns	<0.01	<0.001
CV%	9.42	9.48	8.22	1.46
Grand mean	362.94	297.66	442.28	324.27

Note: The common letter(s) within the column indicate non-significant difference based on Duncan Multiple Range Test (DMRT) at 0.05 level of significance, ** significant at 1% level of significance, *** significant at 0.1% level of significance. (S. Em – Standard Error of mean, CV – Coefficient of Variation, LSD – Least Significance Difference)

Fresh stover yield

The analyzed data revealed that the fresh Stover yield is significantly ($p<0.05$) influenced. However, the highest fresh Stover yield was recorded on the treatment T6, primed with DAP for 18 hours (2954.07) and the lowest fresh stover yield was recorded in T7, priming with salt (1880.741).

Fresh Biomass yield

The analyzed data revealed that the fresh biomass yield is significantly ($p<0.05$) influenced. However, the highest fresh biomass yield was recorded in treatment T6, primed with DAP for 18 hours (6336.29) and the lowest Fresh biomass yield was recorded in T7, priming with salt for 12 hours performed (4085.18).

Harvest index

The analyzed data revealed that the harvest index is significantly ($p<0.05$) influenced. However, the highest harvest index was recorded on the treatment T4, primed with cow-urine for 18 hours (0.62) but statistically

similar (at par) with T7, and the lowest harvest index was recorded in T8, control no priming performed (0.49) (*Table* **5**).

Table 5. Effect of seed priming on fresh kernel yield, adjusted kernel yield, Stover yield, biomass yield, harvest index

Treatment	Stover yield (kg/ha)	Biomass yield (kg/ha)	Harvest index
T1	2564.44^{ab}	5551.55^{b}	0.53^{bc}
T2	2671.29^{a}	5783.14^{ab}	0.52^{c}
T3	2599.36^{ab}	5618.25^{b}	0.52^{bc}
T4	2007.41^{c}	4425.18^{c}	0.62^{a}
T5	2076.94^{bc}	4472.50^{c}	0.53^{bc}
T6	2954.07^{a}	6336.29^{a}	0.49^{c}
T7	1880.74^{c}	4085.18^{c}	0.58^{ab}
T8	2920.37^{a}	5882.22^{ab}	0.49^{c}
LSD (0.05)	506.85	666.40	0.06
S. E_m (±)	167.10	219.70	0.01
F-probability	<0.01	<0.001	<0.01
CV%	11.76	7.22	6.36
Grand Mean	2459.33	5269.29	0.53

Note: The common letter(s) within the column indicate non-significant difference based on Duncan Multiple Range Test (DMRT) at 0.05 level of significance, ** significant at 1% level of significance, *** significant at 0.1% level of significance. (S. Em – Standard Error of mean, CV – Coefficient of Variation, LSD – Least Significance Difference)

According to (S, K, & K, 2014) reported that seeds treated with cow urine (5%) resulted in in increasing the germination rate and a higher germination percentage in paddy. Cow urine which consists of iron, urea, uric acid, estrogen, and progesterone has been observed to influence the inhibitory effects on seed germination, seedling vigor and growth of shoot (Dilrukshi, H.N.N, Perera, A.N.F, 2009). The study of (Shrestha, Pradhan, Shrestha, & Subedi, 2019) showed that the germination index was highest in 24-hour urine-based priming in maize. Urea and Urine priming helped in improving the germinat ion and growth parameters of maize when compared to MOP, hydro-primed, salt and un-primed seeds (Shrestha, Pradhan, Shrestha, & Subedi, 2019). The result was found consistent to (Tian, et al., 2014) where he reported that there were no significant differences in plant height observed between the priming and controlled groups. However, this result was not found before (Shivamurthy & Patil, 2010) seed treated with cow urine priming recorded significantly greater plant height and greater number of green leaves. Cow urine treated seeds increases growth parameters due to the proper maintenance of high-water content in the cell, increased cell division and elongation of cell (Shivamurthy & Patil, 2010).

The results are not in line with (Wolie, Zewudie, & Feleke, 2017) as their research indicated that hydro-primed seeds were earlier in emergence and heading as compared to the cow urine-primed seeds in wheat. Seeds treated with urine showed improved yield due to the presence of plant nutrients including N, P, K, and micronutrients (Schouw, S, Mosbaek , & Tjell, 2002). As mentioned by (D, Tripathi, & Joshi, 2002) and (Harris, Tripathi, & Joshi, 2002) pre-soaking followed by surface drying in field crops is considered to be more advantageous. However, as (Giri & Schillinger, 2003) the result is not in line with their research as there was no significant impact of priming on the grain yield of wheat cultivars. (D, Tripathi, & Joshi, 2002) reported that similar results were obtained in Pakistan and Zimbabwe where seed priming helped to boost the maize yield of grain by 17-76% and 14% when compared with non-primed ones.

CONCLUSIONS

Better germination, early tasseling, silking, maturity, and crop production are all enhanced by seed priming. It is evident that using various priming treatments has been shown to increase the yield of crops. The best germination qualities for seedlings were obtained with an 18-hour cow urine solution priming. However, cow urine solution primed for 18 hours leads to earlier tasseling and silking as well as having a positive effect on yield. Also, as compared to no priming, it resulted in the least preferable germination characteristics of seedlings. All other priming treatments performed better than control or no priming. This study suggests, seed priming with cow urine solution as an easy and cost-effective technique for improving the germination and yield of maize crop.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

AUTHOR CONTRIBUTIONS

Prashna Budhathoki designed the experiments, collection & analyzed the data, wrote the paper. Shreejan Kumar Pandey designed the experiments, collection of data. Shiva Shankar Bhattarai & Prakash Ghimire provided guidance to undertake the work. All authors provided feedback on the manuscript with significant input from all co-authors.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

Ahammad K., Rahman M., and Ali M. 2014. Effect of hydro priming methodon maize (*Zea mays*) seedling emergence. *Bangladesh Journal of Agricultural Research*.**39**(1):43-150

Ambika S., Balakrishnan K and Sujatha K. 2014. Enhancing the seed germination and vigour in coarse cereals by bovine urines. *Journal of*

Agroecology and Natural Resource Management, **1**(2): PP 40-43.199

Diary, K. 2078. Krishi Diary. Hariharbhawan, Lalipur: MOALD.

Dilrukshi, H.N.N. and Perera, A.N.F. 2009. Evaluation of an ancient technique to diagnose the pregnancy in cattle using urine. *Wayamba J. Anim. Sci.*, 1: 6-8.

Ghimire, Y. N., Timsina, K. P., Devkota, D., Gautam, S., Choudhary, D., Poudel, H., & Pant, J. 2018. Dynamics of maize consumption and its implication to maize technology demand in Nepal.

Giri, G. S., & Schillinger, W. F. 2003. Seed Priming Winter Wheat for Germination, Emergence, and Yield. *Crop Science*, 2135-2141.

Harris, D., Tripathi, R., & Joshi, A. 2002. On-farm seed priming to improve crop establishment and yield in dry direct-seeded rice. International Research Institute, Manila, Philippines, 231-240.

Karki, T. B., Shrestha, J., Achhami, B. B., & KC, G. 2015. Status and prospects of maize research in Nepal. *Journal of Maize Research and Development*, **1**(2), 1-9

Koirala, K. B. 2017. Effect of seed priming on maize in the western hills of Nepal. *International Journal of Applied Sciences and Biotechnology*, **5:** 470-478.

MoAD 2014. Statistical Information on nepalese agriculture, Ministry of Agricultural Development, 2014.

MOAD.2017. Statistical information on nepalese agriculture. Ministry of Agriculture and Livestock Development, Singha Durbar, Kathmandu, Nepal.

Ranum, P., Peña-Rosas, Pablo, J., Garcia-Casal, Nieves, & Maria. 2014. Global maize production, utilization, and consumption. *Annals of the new York academy of sciences*, 105-112.

Sapkota, D., & Pokhrel, S. 2010. Community based maize seed production in the hills and mountains of Nepal: A review. Agronomy Journal of Nepal, 107-112.

Schouw, N. L., S, D., Mosbaek , H., & Tjell, J. C. 2002. Composition of human excreta--a case study from Southern Thailand. *Sci Total Environ*. doi:10.1016/s0048-9697(01)00973-1

Shivamurthy, D., & Patil, B. 2010. Effect of Method of Planting and Seed Treatment on Performance of Wheat Genotypes Under Rainfed Condition. Karnataka Journal of Agricultural Science.

Shrestha, A., & Shrestha, j. 2017. Production, Problems and Decision Making Aspects of Maize Seed Producers in Banke District, Nepal. Azarian *Journal of Agriculture*, 212-216.

Shrestha, A., Pradhan, S., Shrestha, J., & Subedi, M. 2019. Role of seed priming in improving seed germination and seedling growth of maize (*Zea mays* L.) under rain fed condition. *Journal of Agriculture and Natural Resources*, **2:** 265-273.

Soleimanzadeh, H. 2013. Effect of seed priming on germination and yield of corn. International *Journal of Agriculture and Crop Sciences*, 366.

Sudozai, M. I., Tunio, S., Chachar, Q., & Rajpar, I. 2013. Seedling establishment and yield of maize under different seed priming periods abd available soil moisture. *Sarhad Journal of Agriculture*, **29**(4), 515--528.

Tian, Y., Guan, B., Zhou, D., Yu, J., Li, G., & Lou, Y. 2014. Responses of seed germination, seedling growth, and seed yield traits to seed pretreatment in maize (*Zea mays* L.). The Scientific World Journal.

Wolie, A. W., Zewudie, D. A., & Feleke, T. T. 2017. Evaluation of seed priming and coating on emergence, yield and yield components of bread wheat. *Ethiopia Journal Science & Technology*, 123-136.

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Research Article

Effect of integrated nutrient management on the cauliflower yield and soil properties

Prabin Chaudhary[1], Prakash Khanal[2*], Keshab Raj Pande[1], Kishor Chandra Dahal[1], Bhaba Prasad Tripathi[1], Pujan Khanal[3], Katapyu Chaulagain[2] and Pawan Dhakal[1]
[1]*Institute of Agriculture and Animal Science, Tribhuvan University, Kritipur, Kathmandu, Nepal*
[2]*Institute of Agriculture and Animal Science, Prithu Technical College, Lamahi, Dang Deukhuri, Nepal*
[3]*Rama University, Kanpur, Uttar Pradesh, India*
**Corresponding author e-mail: prakash.khanal744@gmail.com*
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ABSTRACT
Cauliflower is one of the most important and preferred vegetables and effective nutrient management is essential to improve production as well as soil properties. Thus, the study was conducted to examine the impact of integrated nutrient management on cauliflower and soil at Ghorahi, Dang district of Nepal. The single-factor experiment was organized employing a Randomized Complete Block Design with three replications. In this study, nitrogen (N) was applied through different sources viz 100% N via urea, 50% N via urea + 50% N via farmyard manure, 50% N via urea + 50% N via pig manure, 50% N via urea + 50% N via vermicompost, 50% N via urea + 25% N via farmyard manure + 25% N via pig manure, 50% N via urea + 25% N via pig manure + 25% N via vermicompost, 50% N via urea + 25% N via farm yard manure + 25% N via vermicompost and 50% N via urea + 50% N via (farmyard manure + pig manure + vermicmpost in 1:1:1). Among different treatments, 50% N via urea + 50% N via vermicompost recorded the highest curd diameter (17.72 cm), curd height (11.57 cm), curd weight (0.76 kg), curd yield per hectare (31.67 t ha^{-1}), soil organic matter (3.31%), total nitrogen (0.157%), available phosphorus (76.78 kg ha^{-1}) as well as available potassium (860.20 kg ha^{-1}). Therefore, it is suggested to apply 50% N via urea and 50% N via vermicompost for better cauliflower production and soil properties.
Keywords: Integrated nutrient management, cauliflower, yield, soil properties.

INTRODUCTION
Cauliflower (*Brassica oleracea* var. *botrytis* L.) belonging to the family Cruciferae is an important cole crop in many countries of the world. Cauliflower is cultivated for its white tender curd. The curd is used as salad, vegetables, curries and pickles and is also used in the preparation of fried snacks, burgers and sandwiches in restaurants (Ashraf et al., 2017). Cauliflower is considered as a vital food as 100 g of consumable cauliflower has 51 IU vitamin A, 56 mg vitamin C, 0.10 mg riboflavin, 0.04 mg thiamin, 1.0 mg nicotinic acid, 33 mg calcium, 57 mg phosphorus, 138 mg potassium, 90.8 g moisture, 4.0 g carbohydrates, 2.6 g protein, 0.4 g fat, 1.2 g fibre and 1.5 mg iron (Fageria et al., 2012). In Nepalese kitchens, cauliflower is one of the highly preferred vegetables. Nepal has diverse agroecological conditions due to which year-round cultivation of cauliflower can be done in Nepal (Neupane et al., 2020). In Nepal, cauliflower was cultivated in an area of 39,214 hectares in the period 2021/22 with a production of 611,015 tonnes (MoALD, 2023). In Dang, cauliflower was cultivated on 465 hectares of land in the period 2021/22 with a production of 8,556 tonnes (MoALD, 2023).

Cauliflower is a nutrient-demanding crop so a greater amount of nutrients is required for its better growth and yield. Nowadays the main source of nutrients is inorganic fertilizers but using only inorganic fertilizers for long periods can lead to nutritional imbalance and adverse impacts on the production, environment, soil properties and human health so it is necessary to find a sustainable and environment-friendly alternative method that improves production, environment, soil quality and human health. Thus, integrated nutrient management is a sustainable and environment-friendly option for crop production instead of relying solely on chemical fertilizer. Integrated nutrient management incorporates a combination of organic and inorganic sources of nutrients for plants, resulting in improved production of crops, soil quality and human health (Bhattarai et al., 2012). Integrated nutrient management means using inorganic, organic and biological sources of nutrients at the best level for obtaining and sustaining optimum yield without causing harm to the soil ecosystem and environment (Basnet et al., 2021). Integrated nutrient management is a vital technique that is gaining popularity as well as enhancing crop productivity by

balancing soil's physical, chemical and biological characteristics for the development of the plant (Chaudhary et al., 2023).

Combining organic manures in appropriate quantity along with inorganic fertilizers boosts the growth of the crop (Kumar et al., 2009). In vegetables integrating organic manures along with NPK results in superior crop yield and macronutrient (NPK) availability (Kumar and Sharma, 2004). Chahal et al. (2019) concluded that the soil health and economic yield of cauliflower can be improved by the use of organic inputs through integrated nutrient management. Neupane et al. (2020) also concluded that integrated nutrient management has a better effect on crop growth parameters, root growth parameters and residual soil characteristics compared to the sole use of chemical fertilizers. Considering these facts, this experiment was carried out to examine the effect of different combinations of integrated nutrient management on the cauliflower yield as well as soil properties.

MATERIALS AND METHODS

Study site

A study was conducted in the field of a farmer at Ghorahi, Dang district of Nepal spanning from October 2022 to January 2023. Geographically, the experimental site is located at about 28° 02' N latitude and 82° 29' E longitude with an elevation of about 700 meters above sea level. The site experiences an average annual temperature of 25.03 °C, rainfall of 193.78 mm and relative humidity of 43.71%.

Soil sampling before the experiment

Before planting cauliflower, the soil characteristics of the experimental field were assessed. For that, the soil samples of the experimental field were taken randomly in a zigzag pattern at a depth of 0-15 cm with the help of an auger. Twelve soil samples were taken from the whole experimental field and mixed in a clean bucket to form a composite soil sample. All the debris, pebbles and gravel present in the soil were removed followed by air-drying, grinding and sieving the soil through a 2 mm mesh. Then the soil was poured on the piece of clean paper, spread evenly and divided into four quarters. Among the four quarters, the two quarters positioned opposite were excluded, while the remaining two were mixed again and the same process was conducted repeatedly until there was only half a kilogram of soil remained. After that soil was collected in a clean bag and subjected to a soil test to analyze initial soil properties at Agricultural Technology Center Pvt. Ltd. Laboratory, Lalitpur, Nepal. Various soil properties were assessed using laboratory techniques (Table 1). The soil fertility status of the field before planting of cauliflower is given in Table 2.

Nursery raising

Snow Mystique variety of cauliflower was used for the study. Seedlings were grown on a raised nursery bed (2 m × 1 m) on 17th October 2022. The first irrigation was applied immediately after sowing of seed by using a rose can while the rest of the irrigations were applied depending on the dryness of the soil. Weeds appearing in the nursery were eliminated by hand weeding.

Table 1. Laboratory techniques used to examine various soil properties

Parameters	Analysis techniques
Soil organic matter	Walkley-Black method (Walkley and Black, 1934)
Total Nitrogen	Kjeldahl method (Kirk, 1950)
Available phosphorus	Spectrophotometer (Olsen et al., 1954)
Available potassium	Ammonium acetate method (Simrad, 1993)

Table 2. Soil examination report of the field before planting of cauliflower

Parameters	Value
Soil organic matter	1.65%
Total Nitrogen	0.07%
Available phosphorus	127.00 kg ha^{-1}
Available potassium	718.00 kg ha^{-1}

Approaches to experimentation

The study was conducted using a single-factor Randomized Complete Block Design (RCBD), with three replications and each replication comprised eight treatments. The field was ploughed using a chisel plough and levelled with a planker for the experiment. The entire experimental field covered a space of 272.25 m^2, with each plot measuring 6.075 m^2 (2.70 m × 2.25 m). The spacing of 1 m was maintained between replications while 0.5 m was maintained between treatments. Healthy seedlings that were 30 days old and in uniform condition were chosen for transplanting. In the individual plot of each replication, 30 numbers of plants were transplanted in which a distance of 0.45 m was maintained between plants and a distance of 0.45 m was also maintained between rows. Nitrogen, phosphorus and potassium were administrated at rates of 200 kg, 120 kg and 80 kg per hectare respectively based on Singh and Bhandari (2015). Single super phosphate was used to provide phosphorus, while potassium was delivered via muriate of potash. Both phosphorus and potassium were provided as a basal dose in their entirety. The nitrogen (N) was applied through chemical and various organic sources (Table 3). The entire number of organic sources of nitrogen was applied to their respective plots 15 days before seedlings transplantation while chemical sources of nitrogen were split into two doses i.e. half dose was applied initially as basal dose while the remaining half was provided after 30 days of seedlings transplantation.

Data collection

Data related to different yield parameters like curd diameter, curd height, curd weight and curd yield per hectare were recorded. For that, five representative plants from the inner rows of each treatment of each replication were randomly labelled and tagged. Plants were only labelled from the inner rows to prevent the

influence of the border. The diameter of curds of tagged plants of each treatment of each replication was measured with measuring tape and the average value of curd diameter was calculated and expressed as curd diameter in centimetres (cm). For curd height, the curds harvested from tagged plants of each treatment of each replication were cut into two halves from the centre and the vertical height of the curd was measured with measuring tape and the average value of curd height was calculated and expressed as curd height in centimetre (cm). Further, for curd weight, the weight of curds harvested from tagged plants of each treatment of each replication was weighed by digital weighing balance and the average value of curd weight was calculated and recorded as the curd weight in kilogram (kg). The average value of the curd yield of each treatment of each replication was calculated and based on that average value of the curd yield of each treatment of each replication, the average value of curd yield per hectare of each treatment of each replication was calculated and expressed as curd yield per hectare in tonnes per hectare (t ha^{-1}).

Table 3. Treatment details

Treatments	Treatments details
T1	100% N via urea
T2	50% N via urea + 50% N via farmyard manure
T3	50% N via urea + 50% N via pig manure
T4	50% N via urea + 50% N via vermicompost
T5	50% N via urea + 25% N via farmyard manure + 25% N via pig manure
T6	50% N via urea +25% N via pig manure + 25% N via vermicompost
T7	50% N via urea + 25% N via farmyard manure + 25% N via vermicompost
T8	50% N via urea + 50% N via (farmyard manure + pig manure + vermicompost in 1:1:1)

Moreover, soil characteristics were also examined after the final crop harvest. For that, five soil samples from individual treatments of each replication were taken randomly in a zigzag fashion at a depth of 0-15 cm after the final crop harvest by using an auger. Then five samples taken from individual treatments of each replication were combined in separate individual buckets to create a composite soil sample for individual treatments of each replication. Following this, air-drying, grinding and sieving of the soil through a 2 mm mesh was done. Then the soil of individual treatments of each replication was poured on the individual piece of clean paper, spread evenly and divided into four quarters. Among the four quarters, the two opposite quarters were rejected while the rest were mixed again and the same process was conducted repeatedly until there was only half a kilogram of soil remained for individual treatment of each replication. After that soil of individual treatment of each replication was collected separately in an individual clean bag with proper labelling and subjected to soil test to find out soil properties at Agricultural Technology Center Pvt. Ltd. Laboratory, Lalitpur, Nepal. Various soil properties were assessed through laboratory techniques (Table 1).

Statistical assessment

Data was assessed with the help of R studio. Analysis of Variance (ANOVA) in Randomized Complete Block Design (RCBD) was employed to ascertain the significance level. The treatment means were compared at probabilities of 1% and 5% following the approach outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSIONS

Yield parameters

Curd diameter

The curd diameter was significantly influenced by the different treatments (Table 4). Among various treatments, T4 (50% N via urea + 50% N via vermicompost) showed the highest curd diameter (17.72 cm) followed by 17.15 cm at T6 (50% N via urea + 25% N via pig manure + 25% N via vermicompost) and the lowest curd diameter (12.49 cm) was noted at T1 (100% N via urea). The highest curd diameter in T4 might be because both macro and micro-nutrients are present in vermicompost and the absorption of such macro and micro-nutrients has beneficial impacts on the chlorophyll levels found in leaves (Rekha et al., 2018) and thus increased chlorophyll levels produce more photosynthesis which diverts for curd growth as a result curd obtained better nutrition which ultimately increased curd diameter (Thapa et al., 2022). Further, vermicompost supplies all the necessary macro and micro elements to plants that are needed to complete their lifecycle which ensures proper source-sink relationship for better growth and development (Gyawali et al., 2022). Ali et al. (2018) in cauliflower and Kaur and Kaur (2022) in cauliflower obtained the maximum curd diameter with the combined application of chemical fertilizer and vermicompost.

Curd height

Different treatments showed a significant effect on curd height (Table 4). The maximum curd height (11.57 cm) was observed at T4 (50% N via urea + 50% N via vermicompost) followed by 10.39 cm at T6 (50% N via urea + 25% N via pig manure + 25% N via vermicompost) in contrast the minimum curd height (7.23 cm) was obtained in treatment T1 (100 % N via urea). The highest curd height in T4 might be because vermicompost enhances plant development by providing micro and macronutrients, vitamins, enzymes and hormones and regulating the physico-chemical properties of soil (Makulec, 2002; Sinha et al., 2009; Hazra, 2016). Similarly, essential nutrients present in vermicompost are directly taken by plants (Pathma and Sakthivel, 2012; Lim et al., 2015) which might have contributed to increasing curd height. Furthermore, it has been scientifically confirmed that vermicompost is an effective promoter of plant growth (Chaoui et al., 2003; Guerrero, 2010). Jahan et al. (2014) observed the

maximum curd height of cauliflower when chemical fertilizer was combined with vermicompost.

Curd weight

Various treatments demonstrated a significant impact on curd weight (Table 4). In terms of curd weight, the highest curd weight (0.76 kg) was noted at T4 (50% N via urea + 50% N via vermicompost) which was followed by 0.72 kg at T6 (50% N via urea + 25% N via pig manure + 25% N via vermicompost) but the lowest curd weight (0.43 kg) was noted at T1 (100% N via urea). Here, T4 recorded the highest curd weight which might be because the application of vermicompost along with inorganic fertilizers might have enhanced the physical environment, nutrient provision and a proliferous root system leading to improved uptake of water and nutrients (Neupane et al., 2020). Neupane et al. (2020) in cauliflower and Kannaujiya et al. (2023) in cauliflower also achieved the highest curd weight through the combined use of chemical fertilizers and vermicompost.

Curd yield per hectare

Various treatments showed significant impacts on curd yield per hectare (Table 4). Among various treatments, T4 (50% N via urea + 50% N via vermicompost) showed the maximum curd yield per hectare (31.67 t ha^{-1}) which was followed by 29.81 t ha^{-1} at T6 (50% N via urea + 25% N via pig manure + 25% N via vermicompost). Further, the minimum curd yield per hectare (17.87 t ha^{-1}) was obtained at T1 (100% N via urea). The highest curd yield in T4 might be because vermicompost contributes towards the balanced C: N ratio and improves the essential plant nutrients availability which increases the rate and efficiency of metabolic processes and high assimilation of protein and carbohydrate (Kannaujiya et al., 2023). Similarly, vermicompost provides necessary plant nutrients and plays a vital role in the growth and curd yield of cauliflower (Ali et al., 2018). Similarly, Kaur and Kaur (2022) mentioned that vermicompost acts as a natural fertilizer that does not harm soil and crops as well as improves the yield and quality of cauliflower. Further, adding vermicompost to inorganic fertilizers creates suitable chemical properties of soil for cauliflower production (Ali et al., 2018). Wani et al. (2010) in cauliflower, Mohanta et al. (2018) in broccoli, Neupane et al. (2020) in cauliflower and Kannaujiya et al. (2023) in cauliflower achieved the maximum yield by employing a combination of chemical fertilizers and vermicompost.

In this context, every treatment receiving both inorganic fertilizer and organic manure showed higher curd diameter, curd height, curd weight and curd yield per hectare than T1 which might be because organic manures help to boost the physical, chemical and biological characteristics of soil which enhance nutrient absorption by plants and give better development of the curd (Neupane et al., 2020). Further, it might be due to greater nutrient accessibility during the entire growth period and the effectiveness of chemical fertilizers is also significantly improved when chemical fertilizers are blended with organic manures (Kannaujiya et al., 2023). Further, the combination of both organic manures and chemical fertilizer enhances all yield and quality parameters of the cauliflower (Kaur and Kaur, 2022).

Table 4. Effects of various treatments on cauliflower yield parameters

Treatments	Curd diameter (cm)	Curd height (cm)	Curd weight (kg)	Curd yield per hectare (t ha^{-1})
T1	12.49e	7.23d	0.43d	17.87d
T2	13.65de	8.06cd	0.45d	18.74d
T3	15.49bc	8.90bc	0.60c	25.03c
T4	17.72a	11.57a	0.76a	31.67a
T5	14.46cd	8.40cd	0.57c	23.85c
T6	17.15a	10.39a	0.72ab	29.81ab
T7	16.83a	10.26ab	0.70ab	28.89ab
T8	16.63ab	10.19ab	0.68b	28.31b
Grand mean	15.55	9.37	0.61	25.52
CV%	4.50	8.40	6.60	6.60
F test	***	***	***	***
SEM (±)	0.41	0.45	0.04	0.96

Treatments mean followed by the common letter or letters within the column are not significantly distinct from each other at a significance level of 5%. CV = Coefficient of variation, SEM= Standard error of the mean and *** = Significant at $P \leq 0.001$.

Soil parameters

Soil organic matter

Various treatments demonstrated a significant influence on soil organic matter levels (Table 5). The highest soil organic matter (3.31%) was noted at T4 (50% N via urea + 50% N via vermicompost) followed by 3.17% at T6 (50% N via urea + 25% N via pig manure + 25% N via vermicompost) and the lowest soil organic matter (2.18%) was recorded at T1 (100% N via urea). The highest soil organic matter in T4 might be because vermicompost is enriched with organic carbon and useful organisms which enhances the content of organic matter in the soil (Richards, 1954; Maamori et al., 2023). Similarly, vermicompost contributes to boosting soil's organic matter content (Gupta et al., 2011). Moreover, vermicompost provides plant nutrients, different hormones, enzymes, humic substances and mainly organic matter to the soil (Ceritoglu et al., 2018) and this could have also led to an increase in organic matter. Further, all treatments receiving both organic manure and inorganic fertilizer recorded higher soil organic matter than T1 it is because adding organic manure enhances organic matter (Sedlar et al., 2023).

Total Nitrogen

Different treatments showed significant effects on the total nitrogen (Table 5). In terms of total nitrogen, T4 (50% N via urea + 50% N via vermicompost) recorded the highest total nitrogen (0.157%) followed by 0.144% at T6 (50% N via urea +25% N via pig manure + 25% N via vermicompost) while T1 (100% N via urea) recorded the lowest total nitrogen (0.113%). The highest total nitrogen in T4 might be due to vermicompost's dual action of nitrogen addition to the soil and stimulation of biological nitrogen fixation (Padmavathiamma et al.,

2008). Similarly, vermicompost enhances beneficial microorganisms like bacteria and aerobic fungi in the soil that play a vital role in fixing atmospheric nitrogen (Maamori et al., 2023). K.C. and Bhattarai (2011) and Chahal et al. (2019) also observed the highest nitrogen levels when chemical fertilizer was mixed with vermicompost. Further, all treatments receiving both inorganic fertilizer and organic manure demonstrated higher total nitrogen than T1 which might be because the blending of nitrogen fertilizer with organic manures potentially minimizes the nitrogen losses and boosts the efficiency of fertilizer utilization which upgrades the nitrogen availability (K.C. and Bhattarai, 2011). Despite applying 100% N through urea in T1, the highest total nitrogen was not observed in T1 which might be due to losses from leaching and volatilization, whereas in other treatments the application of organic manure retains the nutrients and minimizes losses (K.C. and Bhattarai, 2011).

Table 5. Effects of various treatments on soil properties after crop harvest

Treatments	Soil organic matter (%)	Total nitrogen (%)	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
T1	2.18c	0.113c	44.64d	497.30c
T2	2.33bc	0.115c	46.02d	510.70c
T3	2.97abc	0.134abc	57.72b	698.90b
T4	3.31a	0.157a	76.78a	860.20a
T5	2.71abc	0.119bc	50.93cd	672.00b
T6	3.17ab	0.144ab	72.35ab	806.40ab
T7	3.08abc	0.143ab	65.23abc	766.10ab
T8	3.06abc	0.143ab	63.00abc	725.80ab
Grand mean	2.85	0.133	59.58	692.17
CV	16.57	10.300	13.60	10.40
F test	**	*	**	***
SEM (±)	0.10	0.014	8.13	71.80

Treatments mean followed by the common letter or letters within the column are not significantly distinct from each other at a significance level of 5%. CV = Coefficient of variation, SEM= Standard error of the mean, * = Significant at $P \leq 0.05$, ** = Significant at $P \leq 0.01$, and *** = Significant at $P \leq 0.001$

Available phosphorus

Available phosphorus was significantly influenced by different treatments (Table 5). Among various treatments, the maximum available phosphorus (76.78 kg ha^{-1}) was recorded at T4 (50 % N via urea + 50% N via vermicompost) followed by 72.35 kg ha^{-1} at T6 (50% N via urea + 25% N via pig manure + 25% N via vermicompost) whereas the minimum amount of available phosphorus (44.64 kg ha^{-1}) was demonstrated by T1 (100% N via urea). The highest available phosphorus in T4 might be because vermicompost has more phosphorus content (Reddy et al., 1999; Mohankumar and Gowda, 2010). Further, during the decomposition process, vermicompost releases organic acids which also contribute to increased phosphorus content (Raju and Reddy, 2000; Meena et al., 2015; Khumukcham et al., 2020). Similarly, vermicompost enhances the solubility and availability of phosphorus by promoting useful microorganisms like bacteria and aerobic fungi in the soil (Maamori et al., 2023). K.C. and Bhattarai (2011), Ali et al. (2018) and Chahal et al. (2019) also observed that the highest available phosphorus was obtained when chemical fertilizer was combined with vermicompost. All treatments receiving both inorganic fertilizer and organic manure exhibited higher levels of available phosphorus than T1, potentially due to the liberation of phosphorus via organic matter after mineralization (Sur et al., 2010). Further, organic matter can enhance the phosphorus availability in the soil through abiotic processes such as decomposition and mineralization of organic phosphorus in soil or ligand exchange (Mabagala and Mngongo, 2022).

Available potassium

Various treatments showed a significant impact on available potassium (Table 5). The highest amount of available potassium (860.20 kg ha^{-1}) was observed on T4 (50% N via urea + 50% N via vermicompost) followed by 806.40 kg ha^{-1} at T6 (50% N via urea +25% N via pig manure + 25% N via vermicompost) while the lowest (497.30 kg ha^{-1}) was noted at T1 (100% N via urea). The highest potassium content in T4 might be because vermicompost adds potassium directly to the potassium pool of the soil (Kumar et al., 2005; Sharma et al., 2009). K.C. and Bhattarai (2011) and Chahal et al. (2019) also recorded the highest available potassium levels when chemical fertilizer and vermicompost were applied together. Here all treatments receiving both inorganic fertilizer and organic manure demonstrated higher available potassium than T1 which might be because organic manures release organic acids at the time of decomposition which mobilizes the non-exchangeable forms of potassium after which potassium is easily available (Chander et al., 2010; Chahal et al., 2019).

CONCLUSIONS

Based on the result of the study, 50% N via urea + 50% N via vermicompost recorded the highest curd diameter, curd height, curd weight, curd yield per hectare, soil organic matter, total nitrogen, available phosphorus and available potassium. Therefore, it is suggested to apply 50% N via urea + 50% N via vermicompost for better cauliflower yield and soil quality.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Ali, S., Kashem, M.A. and Sarker. M.M.H. 2018. Effect of vermicompost on the growth and yield of cauliflower in acid soil of Bangladesh. *Journal of the Sylhet Agricultural University*, **5** (1): 37-43.

Ashraf, M. I., Sajad, S., Hussain, B., Sajjad, M., Saeed, M. S., Sattar, S. and Iqbal, M. A. 2017. Physiological attributes of cauliflower (*Brassica oleracea*) as influenced by the application of different levels of nitrogen and hand weeding. *International Journal of Pure Applied & Bioscience*, **5**(6): 9-13.

Basnet, B., Aryal, A., Neupane, A., K.C., B., Rai, N.H., Adhikari, S., Khanal, P. and Basnet, M. 2021. Effect of integrated nutrient management on growth and yield of radish. *Journal of Agriculture and Natural Resources*, **4**(2): 167-174. https://doi.org/10.3126/janr.v4i2.33712

Bhattarai, D. R., Poudyal, K. and Pokhrel, S. 2012. Effect of *Azotobacter* and nitrogen levels on fruit yield and quality of bell pepper. *Nepal Journal of Science and Technology*, **12:** 29-34.

Ceritoglu, M., Sahin. S. and Erman, M. 2018. Effects of vermicompost on plant growth and soil structure. *Selcuk Journal of Agriculture and Food Sciences*, **32**(3): 607-615. https://doi.org/10.15316/SJAFS.2018.143

Chahal, H.S., Singh, S., Dhillon, I.S. and Kaur, S. 2019. Effect of integrated nitrogen management on macronutrient availability under cauliflower (*Brassica oleracea* var. *botrytis* L.). *International Journal of Current Microbiology Applied Science*, **8**(04): 1623-1633.

Chander, G., Verma, T.S. and Sharma, S. 2010. Nutrient content of cauliflower (*Brassica oleracea* var. *Botrytis* L.) as influenced by boron and farm yard manure in north-west Himalayan alfisols. *Journal of the Indian Society of Soil Science*, **58**(2): 248-251.

Chaudhary, R.P., Kumar, J., Thapa, P., Singh, A., Giri, B. and Kishore, B. 2023. Effect of integrated nutrient management on growth and yield parameter of cauliflower (*Brassica oleracea* var. *Botrytis*) variety Madhuri. *The Pharma Innovation Journal*, **12**(7): 310-314.

Chaoui, H.I., Zibilske, L.M. and Ohno, T. 2003. Effects of earthworms cast and compost on soil microbial activity and plant nutrient availability. *Soil Biology and Biochemistry*, **35**(2): 295–302.

Fageria, M.S., Choudhary, B.R. and Dhaka, R.S. 2012. Vegetable Crops Production Technology. (Volume-II). Kalyani Publication, Noida (UP).

Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for agricultural research. International Rice Research Institute, Laguna, Philippines.

Guerrero, R.D. 2010. Vermicompost production and its use for crop production in the Philippines. *International Journal of Environmental Issues*, **10**(3): 378-383.

Gupta, A.K., Ray, B., Singh, M.P., Upadhyaya, V. and Singh, C.K. 2011. Effect of fertilizers and vermicompost on growth, yield and biochemical changes in *Abelmoschus esculentus*. *Plant Archives*, **11**(1): 285-287.

Gyawali, P., Singh, K. P., Pathak, R. and Bhattarai, B.P. 2022. Effect of integrated nutrient management approach on growth, yield, and economics of cauliflower (*Brassica oleracea* L. *var botrytis*). *Nepalese Horticulture*, **16**(1): 45-54. https://doi.org/10.3126/nh.v16i1.44967

Hazra, G. 2016. Different types of eco-friendly fertilizers: An overview. *Sustainability in Environment*, **1**(1): 54.

Jahan, F.N., Shahjalal, A.T.M., Paul, A.K., Mehraj, H. and Uddin, A.F.M.J. 2014. Efficacy of vermicompost and conventional compost on growth and yield of cauliflower. *Bangladesh Research Publications Research*, **10**(1): 33- 38.

Kannaujiya, A.K., Singh, J.S., Mourya, P.K., Chaudhary, P., Tripathi, A. and Chaudhary, A.K. 2023. Effect of organic manure and inorganic fertilizer on the growth and yield of cauliflower (*Brassica oleracea* var. *botrytis*). *International Journal of Plant & Soil Science*, **35**(23): 590-597.

Kaur, A. and Kaur, H. 2022. Effect of different levels of NPK and manures on growth, yield and quality of cauliflower (*Brassica oleracea* L. var. *botrytis*) under open field conditions. *The Pharma Innovation Journal*, **11**(9): 634-637.

K.C., P. and Bhattarai, B.P. 2011. Effect of integrated nutrient management on the growth, yield and soil nutrient status in tomato. *Nepal Journal of Science and Technology*, **12**: 23-28.

Khumukcham, P.S., Meetei, W.H., Laishram, B. and Hajarimayum, S.S. 2020. Effect of integrated nutrient management on availablemacronutrient status in rapeseed (*Brassica campestris* L.) var. M-27 cultivated soils of Utlou, Manipur. *The Pharma Innovation Journal*, **9**(11): 14-17.

Kirk, P.L. 1950. Kjeldahl method for total nitrogen. *Analytical Chemistry*, **22**: 354–358.

Kumar, A., Sharma, S. and Mishra, S. 2009. Application of farmyard manure and vermicompost on vegetative and generative characteristics of *Jatropha curcas*. *Journal of Phytopathology*, **1**(4): 206-212.

Kumar, P. and S. K. Sharma. 2004. Integrated nutrient management for sustainable cabbage-tomato cropping sequence under mid hill conditions of Himachal Pradesh. *Indian Journal of Horticulture*, **61**(4): 331-334.

Kumar, S., Rawat, C.R., Dhar, S. and Rai, S. 2005. Dry matter accumulation, nutrient uptake and changes in soil fertility status as influenced by different sources of nutrients to forage sorghum (*Sorghum bicolor*). *Indian Journal of Agricultural Sciences*, **75** (6): 340–342.

Lim, S.L., Wu, T.Y., Lim, P.N. and Shak, K.P.Y. 2015. The use of vermicompost in organic farming: overview, effects on soil and economics. *Journal of the Science of Food and Agriculture*, **95**(6): 1143–1156.

Maamori, H.AA., Salman, A.D., Budeiri, M.A., Shami, Y.A.O.A. and Shaabani, E.M.A. 2023. Effect of vermicompost production on some soil properties and nutrients in plants. *IOP Conference Series: Earth and Environmental Science*, **1214**(1): 1-8.

Mabagala, F.S. and Mngongo, M.E. 2022. On the tropical soils; The influence of organic matter (OM) on phosphate bioavailability. *Saudi Journal of Biological Science*, **29**(5): 3635-3641. https://doi.org/10.1016/j.sjbs.2022.02.056

Makulec, G. 2002. The role of *Lumbricus rubellus Hoffm.* in determining biotic and abiotic properties of peat soils. *Polish Journal of Ecology*, **50**(3): 301–339.

Meena, B.P., Kumar, A., Lal, B., Sinha, N.K., Tiwari, P.K., Dotaniya, M.L., Jat, N.K. and Meena, D.V. 2015. Soil microbial, chemical properties and crop productivity as affected by organic manure application in popcorn (*Zea mays* L. var. *evarta*). African *Journal of Microbiological Research*, **9(**21): 1402-1408.

MoALD. 2023. Statistical Information on Nepalese Agriculture. Ministry of Agriculture and Livestock Development (MoALD), Singh Durbar, Kathmandu, Nepal.

Mohankumar, A.B. and Gowda, N.C.N. 2010. Effect of different organic manures and inorganic fertilizers on available NPK, microbial density of the soil and nutrient uptake of brinjal (*Solanum melongena* L.). *An Asian Journal of Soil Science*, **5**(2): 291-294.

Mohanta, R., Nandi, A.K., Mishra, S.P., Pattnaik, A., Hossain, M.M. and Padhiary, A.K. 2018. Effects of integrated nutrient management on growth, yield, quality and economics of sprouting broccoli (*Brassica oleracea var. italica*) cv Shayali. *Journal of Pharmacognosy and Phytochemistry*, **7**(1): 2229-2232.

Neupane, B., Aryal, K., Chhetri, L.B. and Regmi, S. 2020. Effects of integrated nutrient management in early season cauliflower production and its residual effects on soil properties. *Journal of Agriculture and Natural Resources*, **3**(2): 353-365. https://doi.org/10.3126/janr.v3i2.32548

Olsen, S.R., Cole, C.V., Watanable, F.S. and Dean, L. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. Circular no. 939. U.S. Department of Agriculture. Washington, DC, USA.

Padmavathiamma, P. K., Li, L.Y. and Kumari, U.R. 2008. An experimental study of vermi-biowaste composting for agricultural soil improvement. *Bioresource Technology*, **99**(6): 1672–1681. https://doi.org/10.1016/j.biortech.2007.04.028

Pathma, J. and Sakthivel, N. 2012. Microbial diversity of vermicompost bacteria that exhibit useful agricultural traits and waste management potential. *Springer Plus*, **1**(1): 26. https://doi.org/10.1186%2F2193-1801-1-26

Raju, R.A. and Reddy, M.N. 2000. Integrated management of green leaf, compost, crop- residue and inorganic fertilizers in rice (Oryza sativa)-rice system. *Indian Journal of Agronomy*, **45**(4): 629-635.

Reddy, D.D., Rao, A.S., Reddy, K.S. and Takkar, P.N. 1999. Yield sustainability and phosphorus utilization in soyabean- wheat system on vertisols in response to integrated use of manure and fertilizer phosphorus. *Field Crops Research*, **62**: 181-190.

Rekha, G.S., Kaleena, P.K., Elumalai, D., Srikumara, M.P. and Maheswari, V.N. 2018. Effects of vermicompost and plant growth enhancers on the exo-morphological features of *Capsicum annum* (Linn.) Hepper. *International Journal of Recycling of Organic Waste in Agriculture*, **7**(4): 83-88. https://doi.org/10.1007/s40093-017-0191-5

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali. US Department of Agriculture. Agricultural Handbook No. 60, Washington DC.

Sedlar, O., Balik, J., Cerny, J., Kulhanek, M. and Smatanova, M. 2023. Long-term application of organic fertilizers in relation to soil organic matter quality. *Agronomy*, ***13***(1): 175.

Sharma, R. P., Datt, N. and Chander, G. 2009. Effect of vermicompost, farm yard manure and chemical fertilizers on yield, nutrient uptake and soil fertility in okra (Abelmoschus esculentus)–onion (Allium cepa)

sequence in wet temperate zone of Himachal Pradesh. *Journal of Indian Society of Soil Science*, **57**(3): 357– 361.

Simrad, R.R. 1993. Ammonium acetate- extractable elements. In: Soil sampling and methods of analysis. Lewis Publisher, Boca Raton, FL.

Singh, K.P. and Bhandari, R.R. 2015. Cauliflower. Vegetable Crops Production Technology, 1st Edition. Samiksha Publication, Kathmandu, Nepal.

Sinha, R.K., Herat, S., Valani, D. and Chauhan, K. 2009. Vermiculture and sustainable agriculture. *American-Eurasian Journal of Agriculture and Environmental Science*, **5**: 1–55.

Sur, P., Mandal, M. and Das, D.K. 2010. Effect of integrated nutrient management on soil fertility and organic carbon in cabbage (*Brassica oleracea* var. *capitata*) growing soils. *Indian Journal of Agricultural Sciences* **80**(8): 38-41.

Thapa, C., Pandey, S., Kumar, V. and Kumar, M. 2022. Effect of integrated nutrient management on growth and yield characteristics of cauliflower (*Brassica oleracea* var. botrytis L.) cv. Snow Crown. *Biological Forum-An International Journal*, **14**(4): 31-39.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the Chromic Acid Titration Method. Soil Science, **37**(1): 29–38.

Wani, A.J., Mubarak, T. and Rather, G.H. 2010.Effect of organic and inorganic nutrient sources on growth and curd yield of cauliflower (*Brassica oleracea* var. botrytis L.) cv. Snowball-16. *Environ. Ecol.*, **28**(3): 1660-1662.

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Review Article

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Harnessing the Power of Microflora Diversity: Exploring Alternative Solutions to Phosphorus Scarcity in the Soil-Plant System

Sheetanshu Gupta[1], Dhirendra Kumar[2], Milind D. Joshi[3], Santosh Marahatta[4], Aakriti Tamrakar[5], Kumari Sunita[6], Anoop G Zacharia[7] and Wajid Hasan[8*]
[1]*College of Basic Science and Humanities, G.B.P.U.A & T, Pantanagar, UK, India.*
[2]*Department of Botany, Chaudhary Bansi Lal University Bhiwani, Haryana, India.*
[3]*Plant Protection, Agricultural Development Trust's Krishi Vigyan Kendra, Baramati, Maharashtra, India.*
[4]*Department of Agronomy, Faculty of Agriculture, Agriculture and Forestry University (AFU), Chitwan, Nepal*
[5]*Guru Ghasidas vishwavidyalaya, Bilaspur, Chhattisgarh, India.*
[6]*Department of Botany, Deen Dayal Upadhyaya Gorakhpur University Gorakhpur, India.*
[7]*Tamilnadu Agricultural University, Coimbatore, India.*
[8*]*Krishi Vigyan Kendra, Jehanabad, Bihar Agriculture University, Bihar, India*
**Corresponding author e-mail: entowajid@gmail.com*
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ABSTRACT
Phosphorus (P) scarcity poses a significant challenge to sustainable agriculture, impacting plant growth and crop productivity. While arbuscular mycorrhizal (AM) fungi have been extensively studied for their role in enhancing phosphorus acquisition, this review explores the potential of diverse microflora as alternative solutions. The diverse microflora groups, including rhizobacteria, actinomycetes, and cyanobacteria, contribute to phosphorus availability through various mechanisms. These microfloras produce organic acids, enzymes, and chelators that enhance phosphorus solubility and mineralization, facilitating nutrient cycling. Moreover, they promote root growth, nutrient uptake efficiency, and plant growth through the production of growth-promoting substances. Unravelling the molecular interactions between microflora and plants has provided insights into signalling pathways and genetic mechanisms governing the symbiotic association. Harnessing the power of diverse microflora offers potential benefits, including reduced reliance on chemical fertilizers, improved nutrient use efficiency, and environmental sustainability. Future research directions involve exploring unexplored microflora groups, manipulating microbial communities, and integrating microflora-based strategies with precision agriculture technologies. This review highlights the significance of diverse microflora as alternative solutions to address phosphorus scarcity and advance sustainable agricultural practices.
Keywords: Phosphorus scarcity, microflora, alternative solutions, nutrient cycling, sustainable agriculture.

INTRODUCTION

Phosphorus is an essential nutrient for plant growth and is crucial for various biological processes, such as energy transfer, DNA synthesis, and cellular signalling (Elhaissoufi *et al*., 2022; Zeng *et al*., 2022). However, phosphorus scarcity has become a significant challenge in agriculture. The availability of phosphorus in the soil is limited, and the excessive use of phosphorus fertilizers has led to environmental concerns, including water pollution and eutrophication of aquatic ecosystems (Fetahi, 2019; S. Kumar *et al*., 2021; Romanelli *et al*., 2020; Yang *et al*., 2022). The scarcity of phosphorus in agricultural systems affects plant growth and reduces crop productivity. Plants have developed various strategies to cope with phosphorus limitations, such as altering root morphology, enhancing nutrient uptake efficiency, and forming symbiotic associations with beneficial microorganisms (Etesami & Adl, 2020; Jha *et al*., 2023; Singh *et al*., 2023). However, these adaptive mechanisms are often not sufficient to overcome phosphorus scarcity, resulting in reduced crop yields and economic losses for farmers. Microflora, including bacteria, fungi, and archaea, play a crucial role in soil ecosystems and have the potential to enhance phosphorus availability to plants. These microorganisms interact with plant roots and form symbiotic relationships, such as (Li & Cai, 2021; Qi *et al*., 2022). Additionally, certain bacteria possess the ability to solubilize phosphorus from organic and inorganic sources, making it more accessible to plants. The diversity of microflora in the soil is essential for

maintaining soil health and fertility. Different microorganisms have unique capabilities in phosphorus cycling and nutrient acquisition (Harman *et al*., 2021). Therefore, understanding and harnessing the potential of microflora diversity can provide sustainable solutions to address phosphorus limitations in agricultural systems (Sangwan & Prasanna, 2022; Trivedi *et al*., 2020). Despite the potential of microflora diversity in enhancing phosphorus availability, there is still a research gap in fully understanding the complex interactions between microorganisms, plants, and the soil environment(Mitra *et al*., 2022). A comprehensive review of the existing literature is necessary to synthesize the current knowledge and identify the research gaps in this field. The objective of this review are to explore the role of microflora diversity in addressing phosphorus limitations in agricultural systems. By analysing and summarizing the available research, this review aims to provide insights into the mechanisms involved in phosphorus solubilization and uptake by microorganisms, as well as their interactions with plants (Netherway *et al*., 2021). Furthermore, this review will identify the factors influencing microflora diversity and its impact on soil phosphorus availability(Zhang *et al*., 2021). Ultimately, the goal is to highlight the potential applications of microflora diversity in sustainable agriculture and propose future research directions to bridge the existing knowledge gaps.

Diversity of Microflora in Phosphorus Management

Let's have an overview of different types of beneficial microflora beyond arbuscular mycorrhizal fungi, such as rhizobacteria, actinomycetes, and cyanobacteria. The arbuscular mycorrhizal (AM) fungi are well-known for their role in enhancing phosphorus uptake by plants, there are several other types of beneficial microflora that contribute to phosphorus management in agricultural systems. Understanding the diversity and functions of these microorganisms is crucial for harnessing their potential in addressing phosphorus limitations,

Rhizobacteria: Rhizobacteria, also known as plant growth-promoting rhizobacteria (PGPR), are a diverse group of bacteria that colonize the rhizosphere-the region of soil surrounding plant roots. These bacteria establish mutualistic relationships with plants and provide various benefits, including enhanced nutrient availability. Some rhizobacteria possess the ability to solubilize phosphorus by producing organic acids and phosphatases, thereby increasing phosphorus accessibility to plants (Castagno *et al.,* 2021; Sulieman & Mühling, 2021). They also promote root growth and improve nutrient uptake efficiency, contributing to overall plant health and productivity (Griffiths & York, 2020).

Actinomycetes: Actinomycetes are filamentous bacteria that are commonly found in soils. They play a significant role in phosphorus cycling and contribute to soil fertility. Actinomycetes have the capability to produce enzymes, such as phosphatases and phytases, which can hydrolyze organic phosphorus compounds and make them available for plant uptake (Zhang *et al*., 2020) . Moreover, actinomycetes exhibit antagonistic activity against soil borne pathogens, further supporting plant health and growth (Djebaili *et al*., 2020).

Cyanobacteria: Cyanobacteria are photosynthetic microorganisms that can fix atmospheric nitrogen and enhance phosphorus availability in agricultural systems. These bacteria form associations with plants in the form of cyanobacteria symbioses or biofilms on plant surfaces (Prasanna *et al*., 2021). Cyanobacteria symbioses, such as those found in rice paddies, provide a source of fixed nitrogen and contribute to the mobilization of phosphorus through the secretion of organic acids (Kollmen & Strieth, 2022). The presence of cyanobacteria in agricultural soils can significantly impact nutrient cycling and improve overall soil fertility (Rana *et al*., 2020).

The diversity of microflora beyond AM fungi presents a vast array of possibilities for managing phosphorus limitations in agricultural systems (Patwardhan *et al*., 2022). By harnessing the capabilities of rhizobacteria, actinomycetes, cyanobacteria, and other beneficial microorganisms, it becomes possible to enhance phosphorus availability, improve nutrient uptake efficiency, and mitigate the negative impacts of phosphorus scarcity on plant growth and agricultural productivity. The table 1, Shows list of different types of microflora for Phosphorus entrapment.

Table 1. Microflora for Phosphorus entrapment with their significant examples

Representing Microflora Type	Examples
Rhizobacteria	*Bacillus subtilis, Pseudomonas fluorescens, Azospirillum brasilense, Enterobacter spp.*
Actinomycetes	*Streptomyces spp., Frankia spp., Micromonospora spp., Actinoplanes spp.*
Cyanobacteria	*Anabaena spp., Nostoc spp., Oscillatoria spp., Tolypothrix spp., Gloeocapsa spp.*
Myxobacteria	*Sorangium cellulosum, Myxococcus xanthus, Stigmatella aurantiaca, Nannocystis exedens*
Phosphate-Solubilizing Fungi	*Aspergillus spp., Penicillium spp., Trichoderma spp., Mortierella spp.*
Phosphate-Solubilizing Bacteria	*Burkholderia spp., Pseudomonas putida, Bacillus megaterium, Serratia marcescens,*

	Rhizobium leguminosarum
Arthrobacter	*Arthrobacter globiformis,* *Arthrobacter sp.* *Agrobacterium tumefaciens*
Bacillus	*Bacillus subtilis,* *Bacillus licheniformis,*
	Bacillus cereus, *Bacillus thuringiensis*
Azospirillum	*Azospirillum brasilense,* *Azospirillum lipoferum,* *Azospirillum amazonense*
Streptomyces	*Streptomyces coelicolor,* *Streptomyces griseus,* *Streptomyces scabies,* *Streptomyces venezuelae*
Frankia,	*Frankia alni,* *Frankia casuarinae,* *Frankia elaeagni*
Nocardia	*Nocardia brasiliensis,* *Nocardia asteroids,* *Nocardia farcinica*
Clostridium	*Clostridium acetobutylicum,* *Clostridium butyricum,* *Clostridium sporogenes*
Anabaena	*Anabaena azollae,* *Anabaena flos-aquae,* *Anabaena variabilis*
Nostoc	*Nostoc commune,* *Nostoc punctiforme,* *Nostoc verrucosum*

MECHANISMS OF DIVERSE MICROFLORA CONTRIBUTE TO PHOSPHORUS AVAILABILITY AND ACQUISITION IN THE SOIL-PLANT SYSTEM

Various microflora adopts different mechanism for phosphorus availability and acquisition (Fig 1) a brief detail of them is summarized here in Table 2. including Specific names of microorganisms involved in phosphate solubilization and the mechanisms they utilize.

Phosphorus solubilization

Many microflora, including rhizobacteria, actinomycetes, and phosphate-solubilizing fungi, possess the ability to solubilize insoluble forms of phosphorus in the soil (Bargaz *et al*., 2021; Wahid *et al*., 2020). They secrete organic acids, such as citric, gluconic, and malic acids, which chelate and dissolve mineral-bound phosphorus, making them available for plant uptake(Elhaissoufi *et al*., 2022; Vera-Morales *et al*., 2023). Microorganisms, such as phosphate-solubilizing bacteria and fungi, play a crucial role in enhancing phosphorus availability in the soil. These microorganisms secrete organic acids, such as citric, gluconic, and malic acids, as part of their metabolic processes (Bouizgarne *et al*., 2023; Xu *et al*., 2023). These organic acids have the unique ability to chelate metal ions, such as calcium (Ca^{2+}) and aluminum (Al^{3+}), that are bound to phosphorus compounds in the soil. The chelation process involves the formation of stable complexes between organic acids and metal ions. By chelating these metal ions, the microorganisms make the phosphorus compounds more soluble and bioavailable for plants. Moreover, the secretion of enzymes, such as phosphatases, by these microorganisms helps to break down complex phosphorus compounds, such as phytate (myo-inositol hexa-phosphate), into simpler forms like orthophosphate (H_2PO_4- and HPO_4^{2-}) (Sarmah & Sarma, 2023). Orthophosphate, being highly soluble in water, is readily accessible for plant uptake through their root systems. This process is essential for maintaining phosphorus cycling in the ecosystem and ensuring a sufficient supply of phosphorus for plant growth and development(Mayadunna *et al*., 2023). Specific rhizobacteria residing in the rhizosphere, the region surrounding plant roots, contribute to phosphorus solubilization in the soil(Dasila *et al*., 2023). These rhizobacteria release phosphatases enzymes that hydrolyze organic and inorganic phosphorus compounds, converting them into orthophosphate, which is more easily accessible to plants. Fe examples of phosphate-solubilizing rhizobacteria include *Burkholderia cepacia*, *Pseudomonas fluorescens*, and *Rhizobium leguminosarum*. These bacteria work in close association with plant roots, enhancing phosphorus availability for the plants, and supporting their growth and development. The ability of phosphate-solubilizing rhizobacteria to improve phosphorus availability makes them valuable components in sustainable agricultural practices aimed at optimizing nutrient use efficiency(Kumari *et al*., 2023).

Mycorrhizal associations

Arbuscular mycorrhizal (AM) fungi form symbiotic associations with plant roots, extending their hyphae into the soil and increasing the surface area for phosphorus uptake (Sun *et al*., 2023). The fungi acquire phosphorus from the soil and transfer it to the plants in exchange for carbohydrates. This mutualistic relationship enhances phosphorus acquisition and improves plant growth and nutrient uptake efficiency (Doydora *et al*., 2020). Mycorrhizal symbiosis is a mutualistic association between mycorrhizal fungi and plant roots. Mycorrhizal fungi colonize the root cells of most plants and form specialized structures called arbuscular and vesicles (Xu *et al*., 2023). These structures facilitate nutrient exchange between the fungi and the plants. The hyphal network of mycorrhizal fungi extends into the surrounding soil, significantly increasing the nutrient exploration area of the plant root system.

The extensive hyphal network allows mycorrhizal fungi to access phosphorus sources that would be otherwise inaccessible to plant roots. Mycorrhizal fungi secrete various enzymes, including phosphatases, which aid in the release of phosphorus from organic matter in the soil (Song *et al*., 2021). This released phosphorus becomes available for both the mycorrhizal fungi and the associated plants, supporting their nutrient requirements.

In return for the phosphorus and other nutrients absorbed by the mycorrhizal fungi, plants provide them with carbohydrates produced during photosynthesis. This mutualistic relationship enhances nutrient acquisition for both the fungi and the plants and promotes their growth and overall health (Chen *et al*., 2021).

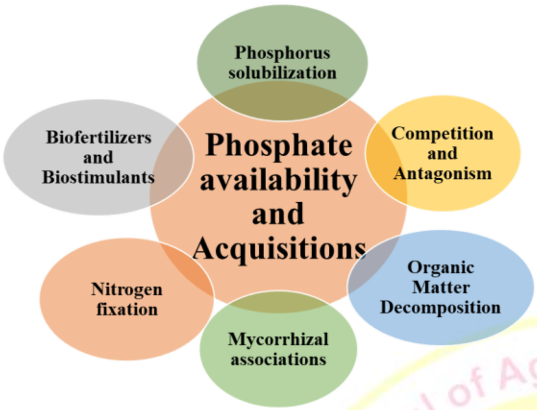

Fig 1. Mechanisms of phosphorus availability and acquisition by microflora

Nitrogen fixation

Certain microflora, such as cyanobacteria and some diazotrophic bacteria, can fix atmospheric nitrogen and convert it into plant-available forms(Wang *et al*., 2021). By providing plants with a nitrogen source, these microflora indirectly contribute to phosphorus acquisition by supporting plant growth and nutrient uptake (Bizos *et al*., 2020; Tortosa *et al*., 2023).Diazotrophic bacteria, such as those belonging to the genera *Rhizobium* and *Bradyrhizobium*, are capable of fixing atmospheric nitrogen (N_2) into a form of nitrogen that plants can use, known as ammonium (NH_4^+.This process occurs in specialized structures called root nodules in legume plants, where a symbiotic relationship forms between the plants and the nitrogen-fixing bacteria (Di *et al*., 2023). Inside the root nodules, the diazotrophic bacteria possess the enzyme nitrogenase, which catalyzes the conversion of atmospheric nitrogen into ammonium. The bacteria utilize fixed nitrogen for their own growth and metabolism. The plants, in turn, benefit from the nitrogen fixation process as they gain access to a usable form of nitrogen, which enhances their overall nutrient status (Yadav *et al*., 2023). The increased nitrogen availability positively influences the plant's growth, indirectly affecting phosphorus uptake efficiency by promoting root development and nutrient absorption capacity (Torres-Cuesta *et al*., 2023).

Organic Matter Decomposition

Microflora, including bacteria and fungi, are key players in the decomposition of organic matter in the soil. These microorganisms secrete a wide range of enzymes, such as celluloses, proteases, and phosphatases, that break down complex organic compounds into simpler forms (Alikhani *et al*., 2023). During the decomposition process, nutrients, including phosphorus, are released from the organic matter into the soil solution. This process is vital for nutrient recycling and contributes to the pool of available phosphorus that can be taken up by plants and other soil organisms (Chen *et al*., 2023). The decomposition of organic matter by microflora also contributes to soil organic matter formation, soil structure improvement, and carbon sequestration, further influencing nutrient availability and ecosystem health.

Biofertilizers and Biostimulants

Biofertilizers and biostimulants harness the potential of specific microorganisms to enhance nutrient availability and uptake in plants. Biofertilizers contain live microorganisms with specific traits, such as phosphorus-solubilizing abilities. For instance, species like *Azospirillum brasilense*, *Burkholderia* spp., and *Pseudomonas spp*. are commonly used in biofertilizers due to their ability to enhance phosphorus availability for plants (Yahya *et al*., 2022). Biostimulants, on the other hand, may not contain live microorganisms but contain substances that stimulate the growth and activity of existing beneficial microflora in the soil. For example, humic substances and seaweed extracts found in biostimulants can positively influence nutrient cycling, including phosphorus availability. The application of biofertilizers and biostimulants promotes sustainable agriculture practices by reducing the reliance on chemical fertilizers and enhancing nutrient use efficiency in plants(Aeron *et al*., 2021).

Competition and Antagonism

Microflora can influence the availability of phosphorus indirectly by competing with less beneficial microorganisms for nutrients and space in the soil environment. Bacteria such as Bacillus subtilis, Streptomyces spp., and *Pseudomonas putida* are examples of microorganisms that exhibit antagonistic behaviors towards harmful pathogens, reducing their population and indirectly benefiting plant health and nutrient uptake(Wang *et al*., 2023). Additionally, beneficial microflora can complete fewer desirable microorganisms, creating a more favorable environment for plant growth and nutrient uptake, including phosphorus. These interactions among microorganisms in the soil have profound implications for nutrient cycling, plant health, and ecosystem productivity (DERMIYATI *et al*., 2023).

MECHANISM OF CHELATION FOR PHOSPHORUS SOLUBILIZATION

Release of Organic Acids: Phosphate-solubilizing microorganisms, including certain species of bacteria and fungi, are equipped with various metabolic pathways that allow them to secrete organic acids into their surrounding environment. These organic acids, such as citric, gluconic, and malic acids, are synthesized by microorganisms as part of their nutrient acquisition and energy production processes (Amarasinghe *et al*., 2022). Encounter with Mineral-Bound Phosphorus: In soils, a significant portion of phosphorus exists in mineral-

bound forms, including calcium phosphate, iron phosphate, and aluminum phosphate. These mineral-bound phosphorus compounds are not directly available for plant uptake and must be converted into soluble forms for plants to absorb(Shaked *et al*., 2023).

Chelation Process: When the organic acids secreted by the microorganisms come into contact with the mineral-bound phosphorus compounds, a chelation process is initiated. Chelation involves the formation of coordination bonds between the carboxylic acid (COOH) groups of the organic acids and metal ions (e.g., calcium, aluminum, iron) that are bound to the phosphorus compounds in the soil (Stala *et al*., 2023).

Formation of Stable Chelates: The carboxylic acid groups in the organic acids have oxygen atoms with lone pairs, which can act as electron donors to form coordination bonds with metal ions. As a result, the metal ions become surrounded and protected by the organic acid molecules, forming stable, water-soluble complexes known as chelates(Shaked *et al*., 2023).

Solubilization of Phosphorus: The chelates formed between the organic acids and metal ions are water-soluble and, therefore, mobile in the soil solution (Richardson & Simpson, 2011.As the chelates move through the soil, they can carry the metal ions and the phosphorus they were bound to in soluble form. The chelation process essentially liberates the phosphorus from the mineral-bound compounds, making it available for plant uptake(Amarasinghe *et al*., 2022).

Enhanced Plant Nutrient Availability: The soluble phosphorus in the form of orthophosphate (H_2PO_4- and HPO_4^{2-}) is now accessible to plant roots. Plants can take up the solubilized phosphorus through their root systems, thereby improving their nutrient status and promoting healthy growth and development (Iqbal *et al*., 2023). A summary of process is given in fig 2.

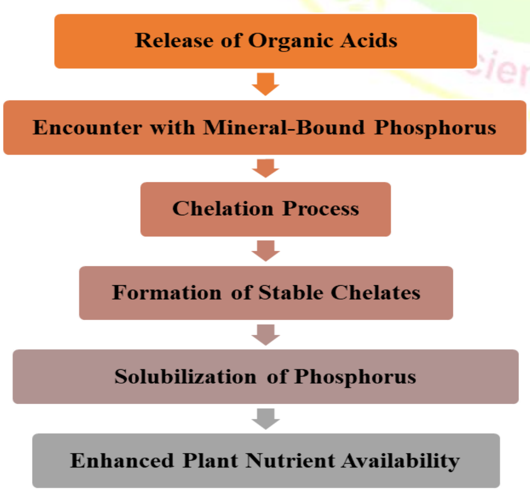

Fig 2. Mechanisms of Chelation for Phosphorus Solubilization

COMPARATIVE ADVANTAGES AND SPECIFIC CHARACTERISTICS OF VARIOUS MICROFLORA GROUPS IN PHOSPHORUS MANAGEMENT

Rhizobacteria: Rhizobacteria are versatile in their ability to promote plant growth and enhance nutrient availability, including phosphorus. They can colonize the rhizosphere, establish beneficial relationships with plants, and solubilize phosphorus through the secretion of organic acids and phosphatases (Chea *et al*., 2021). Rhizobacteria offer the advantage of being easily applicable through seed inoculation or soil application methods (M. Kumar *et al*., 2021).

Actinomycetes: Actinomycetes play a significant role in phosphorus cycling and contribute to soil fertility. They produce a wide range of extracellular enzymes, including phosphatases and phytases, which facilitate phosphorus mineralization (Oyedoh *et al*., 2023). Actinomycetes are particularly efficient in decomposing complex organic matter and releasing phosphorus, making them valuable in nutrient cycling and soil health improvement (Djebaili *et al*., 2021).

Cyanobacteria: Cyanobacteria are photosynthetic microorganisms that form associations with plants and contribute to phosphorus availability through their nitrogen fixation capabilities. They can fix atmospheric nitrogen and secrete organic acids, facilitating phosphorus mobilization in agricultural systems (Briddon *et al*., 2022). Cyanobacteria are particularly beneficial in flooded rice paddies, where they contribute to both nitrogen and phosphorus management (Afkairin *et al*., 2021).

Arbuscular mycorrhizal (AM) fungi: Arbuscular mycorrhizal fungi are well-known for their role in enhancing phosphorus uptake by plants (Etesami *et al*., 2021). They form extensive networks of hyphae that explore the soil, accessing phosphorus sources beyond the reach of plant roots (Ma *et al*., 2021). AM fungi also improve soil structure, water-holding capacity, and nutrient cycling, making them valuable contributors to sustainable phosphorus management (Püschel *et al*., 2021).

Each group of microflora has its own specific characteristics and advantages in phosphorus management, highlighting their diverse roles in enhancing phosphorus availability and acquisition in the soil-plant system. Understanding these mechanisms and comparative advantages can guide the selection and utilization of specific microflora groups in sustainable agriculture practices.

MICROFLORA-MEDIATED PHOSPHORUS MOBILIZATION AND NUTRIENT CYCLING

Mechanisms of Phosphorus Solubilization by Microflora for Organic Acids

Microflora secretes various organic acids, such as citric, gluconic, malic, and acetic acids, which play a crucial role in phosphorus solubilization (Tian *et al*., 2021). Different organic acids may have specific roles in solubilizing phosphorus from different mineral-bound

forms in the soil. For example, citric acid is known to be particularly effective in chelating calcium-phosphate complexes, while gluconic and malic acids may be more effective in releasing phosphorus bound to iron and aluminum. Organic acids work by forming stable complexes with metal ions (e.g., calcium, aluminum) that are bound to phosphorus compounds in the soil. This chelation process releases phosphorus from its mineral-bound state, increasing its solubility in the soil solution (Vera-Morales *et al*., 2023). The organic acid-metal complexes are more water-soluble, making phosphorus readily available for plant uptake. Moreover, organic acids also induce a process called protonation, where they release protons (H^+) into the soil solution. This protonation further promotes the dissolution of mineral-bound phosphorus compounds, increasing the concentration of free orthophosphate ions, which can be easily taken up by plants (El Mazlouzi *et al*., 2022).

Mechanisms of Phosphorus Solubilization by Microflora for Enzymes

Microflora produces various enzymes that are involved in the hydrolysis of both organic and inorganic phosphorus compounds, making phosphorus more accessible to plants. Phosphatases are key enzymes secreted by microorganisms. Among them, acid phosphatases are particularly important in catalyzing the hydrolysis of organic phosphorus compounds, such as phytate (myo-inositol hexakisphosphate), releasing inorganic phosphate (Tian *et al*., 2021). Phosphatases act by cleaving the ester bond between the organic phosphorus compound and its associated group, liberating orthophosphate, which is available for plant uptake. This enzymatic hydrolysis breaks down complex phosphorus compounds into simpler and readily available forms. Phytases are another group of enzymes that contribute to phosphorus solubilization (Chen *et al*., 2019). These enzymes hydrolyze phytic acid, a major form of organic phosphorus found in plant tissues, seeds, and grains. By breaking down phytic acid, phytases release inorganic phosphorus, making it accessible for plant uptake.

Siderophores:

Certain microflora, particularly some bacteria, produce chelating compounds known as siderophores. Siderophores are mainly recognized for their role in iron acquisition but have the ability to form complexes with other elements, including phosphorus, thus enhancing its solubility. The specificity of siderophores for binding to particular phosphorus compounds may vary depending on the bacterial species and environmental conditions (Landa-Acuña *et al*., 2023). Some siderophores may preferentially bind to phosphorus complexes with iron, while others may be more effective in solubilizing phosphorus bound to other metal ions. The exact specificity of siderophores for different phosphorus compounds remains an area of ongoing research and may vary depending on the microbial community and soil conditions. Microflora employs various mechanisms, including the secretion of different organic acids, the production of enzymes (phosphatases, phytases, and phosphodiesterases), and the synthesis of siderophores, to solubilize phosphorus from various mineral-bound forms in the soil.

Table 2. Specific names of microorganisms involved in phosphate solubilization and the mechanisms they utilize.

Microorganism	Acidification	Chelation	Organic Acid Production	Enzymatic Hydrolysis
Pseudomonas fluorescens	✓			
Pseudomonas putida	✓			
Bacillus subtilis	✓			
Bacillus megaterium	✓			
Rhizobium leguminosarum	✓			
Rhizobium etli	✓			
Azospirillum lipoferum	✓			
Azospirillum brasilense	✓			
Burkholderia cepacia	✓			
Burkholderia gladioli	✓			
Enterobacter cloacae	✓			
Enterobacter aerogenes	✓			
Serratia marcescens	✓			
Serratia liquefaciens	✓			
Aspergillus niger		✓	✓	
Aspergillus flavus		✓	✓	
Penicillium citrinum		✓	✓	
Penicillium janthinellum		✓	✓	
Trichoderma harzianum		✓	✓	
Trichoderma viride		✓	✓	
Rhizopus arrhizus		✓	✓	
Rhizopus stolonifer		✓	✓	
Mucor circinelloides		✓	✓	
Mucor hiemalis		✓	✓	
Glomus intraradices				
Glomus mosseae				
Streptomyces griseus				✓
Streptomyces albus				✓
Actinomyces spp.				✓
Frankia spp.				✓
Frankia alni				✓

✓ indicates that the microorganism is known to utilize the corresponding mechanism for phosphate solubilization.

The diversity of these mechanisms allows microflora to efficiently access and release phosphorus, contributing to improved nutrient availability and sustainable agriculture practices (Khoshru *et al*., 2023).

FACILITATION OF PHOSPHORUS MINERALIZATION AND TRANSFORMATION THROUGH MICROBIAL PROCESSES

Decomposition of Organic Matter

Microflora, particularly actinomycetes and phosphate-solubilizing fungi, play a vital role in the decomposition of organic matter in the soil (Bhattacharyya & Furtak, 2022). Organic matter includes plant residues, animal excreta, and other organic materials in the soil. During the decomposition process, microflora secrete a wide range of extracellular enzymes that break down complex organic compounds, releasing organic phosphorus. Actinomycetes are particularly efficient in decomposing complex organic matter. These microorganisms produce a variety of hydrolytic enzymes, including cellulases, hemicellulases, and ligninases, which target the structural components of plant residues. As a result, actinomycetes break down the recalcitrant organic compounds, releasing organic phosphorus as a byproduct. Phosphate-solubilizing fungi, on the other hand, are known to be effective in decomposing organic matter and releasing organic phosphorus through their enzymatic activities. These fungi produce extracellular enzymes, such as phosphatases and phytases, which hydrolyze organic phosphorus compounds present in organic matter, releasing inorganic phosphate and making it available for plant uptake. The decomposition of organic matter by microflora contributes to the mineralization of organic phosphorus into inorganic forms, such as orthophosphate (H_2PO_4- and HPO_4^{2-}.This process ensures that the phosphorus present in the organic matter becomes accessible for plant uptake, ultimately enhancing nutrient availability in the soil (Xiong *et al*., 2023).

Phosphorus Transformation

Microflora, through their enzymatic activities, contribute to the transformation of organic phosphorus compounds into various inorganic forms. As microorganisms metabolize and recycle organic phosphorus, different inorganic phosphate compounds are formed, such as orthophosphate (H_2PO_4- and HPO_4^{2-}), pyrophosphate and polyphosphate. Enzymatic hydrolysis plays a crucial role in these transformations(Tang *et al*., 2023). Phosphatases, produced by microflora, catalyze the hydrolysis of organic phosphorus compounds, breaking them down into inorganic phosphate. For example, acid phosphatases hydrolyze organic phosphates, such as phytic acid, releasing inorganic phosphate. In addition to phosphatases, microorganisms can also carry out other enzymatic processes that contribute to phosphorus transformation. For instance, some microflora possess polyphosphate kinase enzymes, responsible for synthesizing polyphosphate from inorganic phosphate, while others may have pyrophosphates enzymes that break down pyrophosphate into inorganic phosphate. These enzymatic transformations occur as part of microbial metabolic activities and contribute to the cycling and availability of phosphorus in the soil-plant system (Pan *et al*., 2022). The diverse range of inorganic phosphate compounds formed through these microbial processes influences phosphorus availability and uptake by plants, ultimately supporting plant growth and nutrient acquisition (Ducousso-Détrez *et al*., 2022).

ROLE OF MICROFLORA IN NUTRIENT CYCLING AND ORGANIC MATTER DECOMPOSITION

Primarily, the microflora, comprising diverse groups of bacteria, fungi, and other microorganisms, play a vital role in nutrient cycling and organic matter decomposition in soil ecosystems. These processes are intricately linked to the release of bound phosphorus and its availability to plants, contributing to overall soil fertility and sustainable agricultural practices (Yan *et al*., 2023). Secondly, Synergistic Effects of Microflora on Plant Nutrient Assimilation and Utilization Efficiency here the interactions between microflora and plants have a profound impact on enhancing plant nutrient uptake efficiency, contributing to improved plant growth and productivity. Microflora influence nutrient assimilation and utilization through changes in root architecture, production of growth-promoting substances, and cooperative nutrient uptake mechanisms, resulting in enhanced nutrient acquisition and utilization efficiency (Raza *et al*., 2023).

Role of Microflora on Nutrient Cycling

Nutrient cycling is a fundamental ecological process that involves the transformation, recycling, and redistribution of essential elements in the soil (Ndlovu *et al*., 2023). Microflora, including rhizobacteria, actinomycetes, and arbuscular mycorrhizal (AM) fungi, actively participates in nutrient cycling, including phosphorus, nitrogen, and carbon. Rhizobacteria, residing in the rhizosphere, form beneficial relationships with plant roots. These microorganisms have the capability to mineralize organic nitrogen and phosphorus compounds, breaking them down into inorganic forms that can be taken up by plants (Mousavi *et al*., 2023). Their activities contribute to the release of bound phosphorus from organic matter, making it accessible for plant uptake and utilization. Actinomycetes, another group of microflora, are well-known for their ability to decompose complex organic matter, such as plant residues, animal excreta, and lignocellulosic materials. They secrete an array of extracellular enzymes, including cellulases, hemicellulases, and ligninases, which target the structural components of organic matter. Through this enzymatic breakdown, actinomycetes release nutrients, including phosphorus, back into the soil solution, enriching the nutrient pool available for plant uptake (Meena *et al*., 2023). AM fungi form mutualistic

symbiotic associations with the roots of most plants. The hyphal network of AM fungi extensively explores the soil, accessing phosphorus sources that are beyond the reach of plant roots. As a consequence, phosphorus taken up by the fungi can be exchanged with the host plants, promoting nutrient redistribution and cycling in the soil ecosystem. The enhanced phosphorus uptake by plants through this symbiotic association contributes to improved nutrient availability and plant growth (Havlin & Schlegel, 2021).

Role of Microflora on Organic Matter Decomposition

Organic matter decomposition is a key process in soil ecosystems, involving the breakdown of complex organic compounds into simpler forms through the action of microflora. As organic matter decomposes, various nutrients, including phosphorus, are released from organic compounds, making them available for plant uptake and utilization (Gu *et al*., 2023). Actinomycetes, renowned for their efficient decomposition abilities, are major contributors to organic matter breakdown. These microorganisms produce a wide range of extracellular enzymes that target different components of organic matter, such as cellulose, hemicelluloses, and lignin. The enzymatic hydrolysis of these structural components releases bound phosphorus from organic compounds, further contributing to the nutrient pool available for plants. Phosphate-solubilizing fungi also play a significant role in organic matter decomposition and phosphorus release(Finore *et al*., 2023). Their secretion of enzymes, including phosphatases and phytases, aids in the breakdown of organic phosphorus compounds in organic matter. Through this enzymatic activity, phosphate-solubilizing fungi release inorganic phosphate, which becomes readily available for plant uptake. The decomposition of organic matter by microflora contributes to the release of phosphorus from organic forms and its subsequent cycling in the soil-plant system (Garraud *et al*., 2023). This process ensures that phosphorus, once locked in organic compounds, is made accessible for plant roots, supporting plant growth and nutrient acquisition.

Role of Microflora in Cooperative Nutrient Uptake

Microflora, such as rhizobacteria and mycorrhizal fungi, form symbiotic associations with plant roots, establishing mutualistic relationships that benefit both parties (Guan *et al*., 2023). Rhizobacteria, residing in the rhizosphere, interact closely with plant roots and release beneficial substances that promote plant growth and nutrient availability. For example, some rhizobacteria are capable of enhancing the availability of phosphorus, nitrogen, and other essential nutrients through various mechanisms, including the production of organic acids and enzymes (Dong *et al*., 2023). Mycorrhizal fungi, on the other hand, extend their hyphal network into the soil, effectively extending the root's nutrient exploration area. These fungi can access phosphorus and other nutrients that are otherwise beyond the reach of plant roots, facilitating nutrient uptake and transport to the host plant (Li *et al*., 2023). The cooperative nutrient uptake by microflora and plants leads to increased nutrient availability and uptake efficiency, supporting plant growth and development.

Role of Microflora in Improved Nutrient Mobilization

Microflora actively participates in the decomposition of organic matter in the soil, a process crucial for nutrient cycling and nutrient availability. Actinomycetes and phosphate-solubilizing fungi are major contributors to this process, as they secrete a wide array of extracellular enzymes (Beltran-Medina *et al*., 2023). These enzymes catalyze the breakdown of complex organic compounds, releasing bound nutrients, including phosphorus, into the soil solution. The enzymatic activities of microflora facilitate the release of phosphorus and other nutrients from organic compounds, making them accessible for plant uptake. For instance, acid phosphatases produced by microflora can hydrolyze organic phosphorus compounds, converting them into inorganic phosphate, which can be taken up by plant roots. This improved nutrient mobilization enhances the nutrient pool available to plants, supporting their nutritional needs and promoting optimal growth.

Role of Microflora in Nutrient Priming:

Certain microflora, particularly plant growth-promoting rhizobacteria, can induce nutrient-priming effects in plants. The presence of these beneficial microorganisms can trigger physiological and biochemical responses in plants, leading to enhanced nutrient assimilation and utilization efficiency. Through nutrient priming, plants become more efficient in absorbing and utilizing nutrients, including phosphorus(Beltran-Medina *et al*., 2023). This priming effect improves the plant's overall nutrient uptake capacity, enabling better nutrient utilization for growth and development. For example, rhizobacteria can trigger changes in the expression of genes related to nutrient transporters and nutrient uptake in plants, enhancing their ability to acquire and utilize phosphorus.

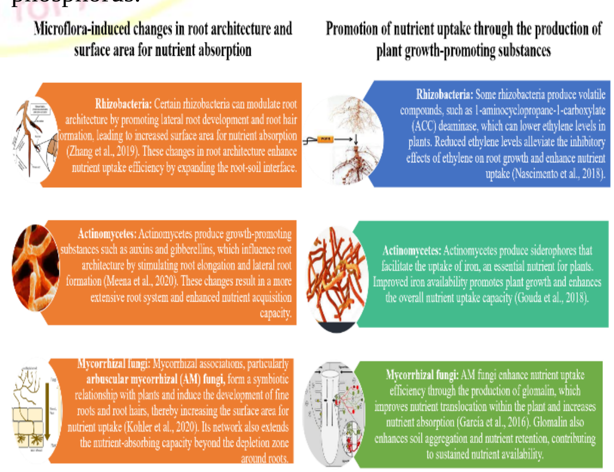

Fig 3. Enhancing Plant Nutrient Uptake Efficiency

UNRAVELLING THE MICROFLORA-PLANT INTERACTION

Signalling Pathways and molecular mechanisms underlying the symbiotic association between Plants and diverse microflora

The interaction between rhizobacteria and plants involves complex signalling pathways. For example, the recognition of specific microbial signals by plant receptors triggers a signalling cascade that leads to changes in gene expression and the activation of defence responses or symbiotic processes (Cataldi *et al*., 2020; Pavlů *et al*., 2018). Common signalling molecules involved in the rhizobacteria-plant interaction include nodulation factors, which promote root nodulation and nitrogen fixation. The Actinomycetes establish associations with plants through the production of plant growth-promoting substances and the modulation of phytohormones. These substances and hormones regulate various plant processes, including root development, nutrient uptake, and stress tolerance. The intricate signalling pathways involved in actinomycetes-plant interactions are still being elucidated. Furthermore, the symbiotic association between mycorrhizal fungi and plants relies on signalling molecules exchanged between the two partners(Pavlů *et al*., 2018). The plant releases strigolactones, which act as signalling molecules to stimulate fungal colonization and the establishment of mycorrhizal symbiosis (Kalia *et al*., 2021). In return, mycorrhizal fungi produce signals that enhance plant nutrient uptake and promote mutual growth benefits (Kalia *et al*., 2021; Xie *et al*., 2022) (fig 4).

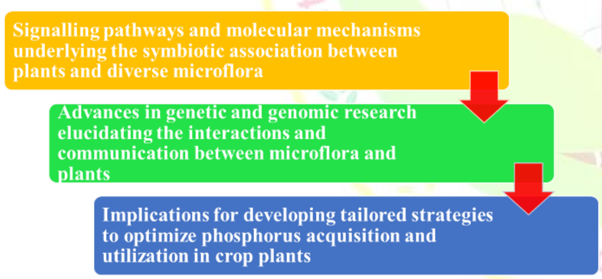

Fig 4. Unravelling the Microflora-Plant Interaction Mechanisms

Advances in genetic and genomic research elucidating the interactions and communication between microflora and plants:

Omics approaches: Recent advances in genetic and genomic research, including transcriptomics, proteomics, and metabolomics, have provided insights into the molecular mechanisms underlying microflora-plant interactions (Vidal *et al*., 2022). These techniques enable the identification of specific genes, proteins, and metabolites involved in the interaction and help decipher the communication and signalling processes between microflora and plants (Mo *et al*., 2022).

Microbiome analysis: High-throughput sequencing technologies have revolutionized the study of plant-associated microflora by enabling comprehensive microbiome analysis. By characterizing the microbial communities associated with plants, researchers can identify key microorganisms and their functional potential in promoting nutrient uptake and plant growth (Chandrasekaran, 2022; Wu *et al*., 2022). This knowledge contributes to our understanding of the complex interactions between microflora and plants.

Implications for developing tailored strategies to optimize phosphorus acquisition and utilization in crop plants:

Targeted microbial inoculation: Understanding the signalling pathways and molecular mechanisms involved in microflora-plant interactions can inform the development of tailored strategies for microbial inoculation (Niu *et al*., 2021). Specific microorganisms that promote phosphorus acquisition and utilization can be isolated and applied as biofertilizers to enhance crop productivity. Selecting microorganisms with the ability to solubilize phosphorus, produce growth-promoting substances, or facilitate nutrient uptake can optimize phosphorus availability for crop plants (Singh *et al*., 2019).

Genetic engineering: Insights gained from genetic and genomic research on microflora-plant interactions can be applied to crop improvement through genetic engineering (Khatri *et al*., 2023). By identifying genes involved in nutrient acquisition and signalling pathways, researchers can potentially enhance phosphorus utilization efficiency in crops (Boorboori & Zhang, 2023; Resendiz-Nava *et al*., 2023). Genetic engineering approaches may include the over expression or manipulation of genes associated with nutrient uptake or the development of improved plant-microbe communication.

SUSTAINABLE AGRICULTURE AND ENVIRONMENTAL BENEFITS

Reduced Reliance on chemical fertilizers and associated environmental risks

Nutrient supplementation: Microflora, such as rhizobacteria, actinomycetes, and mycorrhizal fungi, contribute to nutrient availability and uptake by plants. By enhancing nutrient mobilization, these microflora as reduce the need for excessive chemical fertilizer applications. This reduction in fertilizer usage decreases the risk of nutrient runoff and associated environmental pollution.

Decreased nutrient leaching: Microflora-mediated processes, such as phosphorus solubilization, organic matter decomposition, and nutrient cycling, enhance nutrient use efficiency and minimize nutrient losses through leaching. Microflora helps retain nutrients in the soil, making them more available for plant uptake and reducing the risk of nutrient runoff into water bodies.

Enhanced nutrient use efficiency and minimized nutrient losses through microflora-mediated processes:

Nutrient recycling: Microflora plays a crucial role in nutrient cycling and organic matter decomposition, which release bound nutrients and make them available for plant uptake. By facilitating the recycling of

nutrients, microflora nutrient use efficiency in agricultural systems.

Phosphorus management: Phosphorus is a non-renewable resource, and its efficient use is essential for sustainable agriculture. Microflora contributes to phosphorus solubilization, mineralization, and transformation processes, enhancing their availability for plant uptake. This microflora-mediated phosphorus management improves nutrient use efficiency and minimizes phosphorus losses to the environment.

Nitrogen fixation: Some microflora, such as nitrogen-fixing rhizobacteria, can convert atmospheric nitrogen into plant-available forms, reducing the need for synthetic nitrogen fertilizers. This biological nitrogen fixation process enhances nitrogen use efficiency and reduces the environmental impact associated with nitrogen fertilizer application.

Potential applications of diverse microflora in organic and regenerative farming systems:

Organic farming: Microflora plays a significant role in organic farming systems as they contribute to nutrient cycling, disease suppression, and plant growth promotion. The use of microflora-based biofertilizers and biocontrol agents can help maintain soil fertility, reduce reliance on synthetic inputs, and support organic farming practices.

Regenerative agriculture: Microflora has great potential in regenerative farming systems, which aim to restore soil health, biodiversity, and ecosystem services. The inclusion of diverse microflora in regenerative practices promotes nutrient cycling, improves soil structure, and enhances overall soil health. Microflora contributes to the development of resilient agro-ecosystems that can mitigate climate change impacts and promote sustainable food production.

CONCLUSION

Significance in Phosphorus Cycling and Plant Nutrition

The chelation mechanism plays a vital role in the phosphorus cycle and overall soil fertility. By enhancing phosphorus solubilization, phosphate-solubilizing microorganisms contribute to nutrient cycling and availability in the soil(Vera-Morales *et al*., 2023). This process is particularly important in phosphorus-deficient soils, where the direct availability of phosphorus for plant uptake is limited. Moreover, the chelation process also influences the nutrient dynamics in the rhizosphere, the region surrounding plant roots(Marschner & Rengel, 2023). As phosphate-solubilizing microorganisms thrive in the rhizosphere, they facilitate the release of phosphorus from mineral-bound compounds, increasing the pool of plant-available phosphorus in this critical zone. Overall, the chelation mechanism of organic acids produced by microorganisms represents an essential biological process that promotes sustainable agriculture by improving phosphorus availability, plant nutrition, and overall ecosystem productivity.

Effectiveness of Different Acids in Phosphorus Solubilization:

Microorganisms, such as phosphate-solubilizing bacteria and fungi, secrete organic acids as part of their metabolic processes. These organic acids play a crucial role in solubilizing phosphorus from mineral-bound forms in the soil(Sen *et al*., 2023). One important factor influencing the effectiveness of organic acids in phosphorus solubilization is the number of carboxylic acid (COOH) groups present in the molecular structure. Organic acids with a higher number of COOH groups generally exhibit a stronger chelating capacity, allowing them to form more stable complexes with metal ions. For instance, citric acid ($C_6H_8O_7$) contains three COOH groups and is known to be a potent phosphorus-solubilizing acid. Its ability to form strong chelates with metal ions makes it highly effective in releasing phosphorus from mineral-bound compounds in the soil. Similarly, gluconic acid ($C_6H_{12}O_7$) and malic acid ($C_4H_6O_5$), both containing multiple COOH groups, are also effective in solubilizing phosphorus (Khan *et al*., 2019.On the other hand, organic acids with fewer COOH groups, such as acetic acid (CH_3COOH), may have a limited ability to chelate metal ions and, consequently, lower phosphorus-solubilizing efficiency. Apart from the number of COOH groups, the spatial arrangement of these groups in the molecular structure can also influence the acid's chelation capacity(Ahmad *et al*., 2023). The position of COOH groups affects the acid's ability to bind with metal ions effectively, further impacting its phosphorus-solubilizing potential. Overall, the solubilization of phosphorus by organic acids is a complex process influenced by various chemical interactions between the acids, metal ions, and mineral-bound phosphorus compounds in the soil.

Types of Mineral-Bound Phosphorus in Soil:

Phosphorus in the soil exists in various mineral-bound forms that are not directly available for plant uptake. These forms are part of the soil's phosphorus pool and contribute to the overall phosphorus cycling in the ecosystem(Lu *et al*., 2023).

Apatite: Apatite is a common calcium phosphate mineral found in soils. It is considered relatively insoluble, limiting its direct availability for plants. However, some microorganisms, particularly phosphate-solubilizing bacteria and fungi, have the ability to solubilize apatite through various mechanisms. By releasing organic acids and enzymes, these microorganisms facilitate the breakdown of apatite, making phosphorus available for plant uptake.

Iron and Aluminum Phosphates: In acidic soils, phosphorus can form complexes with iron and aluminum, resulting in the precipitation of iron and aluminum phosphates. These compounds contribute to the pool of mineral-bound phosphorus and may be less available to plants due to their relatively low solubility in acidic conditions.

Organic Phosphorus: A significant portion of soil phosphorus is present in organic forms, such as phytate (Myo-inositol hexa-phosphate) and other organic phosphates. These compounds are often bound to soil

organic matter, and their availability for plant uptake requires enzymatic processes by microorganisms to convert them into simpler forms like orthophosphate.

Calcium Phosphates: Besides apatite, calcium can form other calcium phosphate compounds, such as dicalcium phosphate ($CaHPO_4$) and octa-calcium phosphate ($Ca_8H_2(PO_4)_6 \cdot 5H2O$.These compounds also contribute to the total phosphorus pool in the soil and may undergo solubilization processes mediated by microorganisms to enhance phosphorus availability

Readers can have a recap of the key findings and implications discussed in this review quickly. Throughout this review, we have explored the role of diverse microflora in addressing phosphorus limitations and improving sustainable agricultural practices. Key findings and implications include:

Phosphorus scarcity and its impact: Phosphorus scarcity poses a significant challenge to plant growth and agricultural productivity. Understanding the implications of phosphorus limitations is crucial for sustainable agricultural management.

The potential of microflora diversity: Microflora beyond arbuscular mycorrhizal (AM) fungi, such as rhizobacteria, actinomycetes, and cyanobacteria, have shown potential in addressing phosphorus limitations. These microflora as contribute to phosphorus mobilization, nutrient cycling, and enhanced nutrient uptake efficiency.

Mechanisms of microflora contribution: Microflora mediates phosphorus mobilization through the production of organic acids, enzymes, and chelators that enhance phosphorus solubility and availability. They also facilitate phosphorus mineralization, transformation, and nutrient cycling in the soil-plant system.

Enhanced plant nutrient uptake: Microflora induces changes in root architecture, increase the surface area for nutrient absorption, and promote nutrient uptake through the production of plant growth-promoting substances. They also exhibit synergistic effects on plant nutrient assimilation and utilization efficiency.

SIGNIFICANCE &FUTURE PROSPECTS

Such studies on the diversity of microflora give a new angle towards phosphorus scarcity and improving sustainable agricultural practices to researchers, agronomists, and policymakers seeking alternative solutions to phosphorus management. Diverse microflora offers significant potential in addressing phosphorus scarcity and improving sustainable agricultural practices. By enhancing phosphorus availability, improving nutrient use efficiency, and reducing reliance on chemical fertilizers, microflora contributes to sustainable phosphorus management and promotes environmentally friendly farming systems. Their role in nutrient cycling, organic matter decomposition, and plant-microbe interactions makes them valuable assets for optimizing phosphorus acquisition and utilization in crop plants. This review holds significance for researchers, agronomists, and policymakers involved in phosphorus management and sustainable agriculture. The comprehensive understanding of microflora-mediated processes, mechanisms, and interactions presented here provides insights into alternative solutions for phosphorus acquisition and utilization. The knowledge shared in this review can guide the development of tailored strategies, including microbial inoculation, genetic engineering, and organic farming approaches, to optimize phosphorus availability and enhance agricultural sustainability. This review serves as a valuable resource for those seeking alternative and environmentally friendly approaches to phosphorus management in agriculture.

Data Availability Statement: All data, figures and results in paper are our own and original.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Aeron, A., Dubey, R. C., & Maheshwari, D. K. 2021.Next-Generation biofertilizers and novel biostimulants: Documentation and validation of mechanism of endophytic plant growth-promoting rhizobacteria in tomato. *Archives of Microbiology*, **203**(6), 3715-3726.

Afkairin, A., Ippolito, J. A., Stromberger, M., & Davis, J. G. 2021.Solubilization of organic phosphorus sources by cyanobacteria and a commercially available bacterial consortium. *Applied Soil Ecology*, **162,** 103900.

Ahmad, A., Moin, S. F., Liaqat, I., Saleem, S., Muhammad, F., Mujahid, T., & Zafar, U. 2023.Isolation, solubilization of inorganic phosphate, and production of organic acids by individual and co-inoculated microorganisms. *Geomicrobiology Journal*, **40**(1), 111-121.

Alikhani, H. A., Beheshti, M., Pourbabaee, A. A., Etesami, H., Asadi Rahmani, H., & Noroozi, M. 2023.Phosphorus Use Management in Paddy Fields by Enriching Periphyton with Its Phosphate-Solubilizing Bacteria and Fungi at the Late Stage of Rice Growth. *Journal of Soil Science and Plant Nutrition*, 1-17.

Amarasinghe, T., Madhusha, C., Munaweera, I., & Kottegoda, N. 2022.Review on mechanisms of phosphate solubilization in rock phosphate fertilizer. *Communications in Soil Science and Plant Analysis*, **53**(8), 944-960.

Bargaz, A., Elhaissoufi, W., Khourchi, S., Benmrid, B., Borden, K. A., & Rchiad, Z. 2021.Benefits of phosphate solubilizing bacteria on belowground crop performance for improved crop acquisition of phosphorus. *Microbiological research*, ***252***, 126842.

Beltran-Medina, I., Romero-Perdomo, F., Molano-Chavez, L., Gutiérrez, A. Y., Silva, A. M., &

Estrada-Bonilla, G. 2023.Inoculation of phosphate-solubilizing bacteria improves soil phosphorus mobilization and maize productivity. *Nutrient Cycling in Agroecosystems*, **126**(1), 21-34.

Bhattacharyya, S. S., & Furtak, K. 2022.Soil–plant–microbe interactions determine soil biological fertility by altering Rhizospheric nutrient cycling and biocrust formation. *Sustainability*, **15**(1), 625.

Bizos, G., Papatheodorou, E. M., Chatzistathis, T., Ntalli, N., Aschonitis, V. G., & Monokrousos, N. 2020.The role of microbial inoculants on plant protection, growth stimulation, and crop productivity of the olive tree (Olea europea L..*Plants*, **9**(6), 743.

Boorboori, M. R., & Zhang, H. 2023.The Mechanisms of Trichoderma Species to Reduce Drought and Salinity Stress in Plants. *Phyton (0031-9457)*, *92*(8.

Bouizgarne, B., Bakki, M., Boutasknit, A., Banane, B., El Ouarrat, H., Ait El Maalem, S., Amenzou, A., Ghousmi, A., & Meddich, A. 2023.Phosphate and potash solubilizing bacteria from Moroccan phosphate mine showing antagonism to bacterial canker agent and inducing effective tomato growth promotion. *Frontiers in Plant Science*, **14**, 970382.

Briddon, C. L., Szekeres, E., Hegedüs, A., Nicoară, M., Chiriac, C., Stockenreiter, M., & Drugă, B. 2022.The combined impact of low temperatures and shifting phosphorus availability on the competitive ability of cyanobacteria. *Scientific Reports*, **12**(1), 16409.

Castagno, L. N., Sannazzaro, A. I., Gonzalez, M. E., Pieckenstain, F. L., & Estrella, M. J. 2021.Phosphobacteria as key actors to overcome phosphorus deficiency in plants. *Annals of Applied Biology*, *1782*, 256-267.

Cataldi, M. P., Heuer, S., Mauchline, T. H., Wilkinson, M. D., Masters-Clark, E., Di Benedetto, N. A., Corbo, M. R., & Flagella, Z. 2020.Effect of plant growth promoting bacteria on the growth of wheat seedlings subjected to phosphate starvation. *Agronomy*, **10**(7), 978.

Chandrasekaran, M. 2022.Arbuscular mycorrhizal fungi mediated enhanced biomass, root morphological traits and nutrient uptake under drought stress: A meta-analysis. *Journal of Fungi*, **8**(7), 660.

Chea, L., Pfeiffer, B., Schneider, D., Daniel, R., Pawelzik, E., & Naumann, M. 2021.Morphological and metabolite responses of potatoes under various phosphorus levels and their amelioration by plant growth-promoting rhizobacteria. *International Journal of Molecular Sciences*, **22**(10), 5162.

Chen, H.-F., Chuang, H.-C., & Tan, T.-H. 2019.Regulation of dual-specificity phosphatase (DUSP) ubiquitination and protein stability. *International Journal of Molecular Sciences*, *20*(11), 2668.

Chen, J., Zhao, G., Wei, Y., Dong, Y., Hou, L., & Jiao, R. 2021. Isolation and screening of multifunctional phosphate solubilizing bacteria and its growth-promoting effect on Chinese fir seedlings. *Scientific Reports*, **11**(1), 9081.

Chen, S., Gao, J., Chen, H., Zhang, Z., Huang, J., Lv, L., Tan, J., & Jiang, X. 2023.The role of long-term mineral and manure fertilization on P species accumulation and phosphate-solubilizing microorganisms in paddy red soils. *Soil*, **9**(1), 101-116.

Dasila, H., Sah, V., Jaggi, V., Kumar, A., Tewari, L., Taj, G., Chaturvedi, S., Perveen, K., Bukhari, N. A., & Siang, T. C. 2023.Cold-tolerant phosphate-solubilizing Pseudomonas strains promote wheat growth and yield by improving soil phosphorous (P) nutrition status. *Frontiers in microbiology*, **14**, 1135693.

DERMIYATI, D., SUHARJO, R., TELAUMBANUA, M., YOSITA, R., SARI, A. W., & ANDAYANI, A. P. 2023.Antagonist and plant growth promoting potential of indigenous bacteria isolated from oil palm empty fruit bunches. *Biodiversitas Journal of Biological Diversity*, *242*.

Di, Y.-n., Kui, L., Singh, P., Liu, L.-f., Xie, L.-y., He, L.-l., & Li, F.-s. 2023.Identification and characterization of Bacillus subtilis B9: A diazotrophic plant growth-promoting endophytic bacterium isolated from sugarcane root. *Journal of Plant Growth Regulation*, **42**(3), 1720-1737.

Djebaili, R., Pellegrini, M., Bernardi, M., Smati, M., Kitouni, M., & Del Gallo, M. 2020.Biocontrol activity of actinomycetes strains against fungal and bacterial pathogens of Solanum lycopersicum l. and Daucus carota L.: in vitro and in planta antagonistic activity. Biology and Life Sciences Forum,

Djebaili, R., Pellegrini, M., Rossi, M., Forni, C., Smati, M., Del Gallo, M., & Kitouni, M. 2021.Characterization of plant growth-promoting traits and inoculation effects on Triticum durum of actinomycetes isolates under salt stress conditions. *Soil systems*, *52*, 26.

Dong, J., Jiang, Y., Lyu, M., Cao, C., Li, X., Xiong, X., Lin, W., Yang, Z., Chen, G., & Yang, Y. 2023.Drought changes the trade-off strategy of root and arbuscular mycorrhizal fungi growth in a subtropical Chinese fir plantation. *Forests*, **14**(1), 114.

Doydora, S., Gatiboni, L., Grieger, K., Hesterberg, D., Jones, J. L., McLamore, E. S., Peters, R., Sozzani, R., Van den Broeck, L., & Duckworth, O. W. 2020.Accessing legacy phosphorus in soils. *Soil systems*, **4**(4), 74.

Ducousso-Détrez, A., Fontaine, J., Lounès-Hadj Sahraoui, A., & Hijri, M. 2022.Diversity of

phosphate chemical forms in soils and their contributions on soil microbial community structure changes. *Microorganisms*, **10**(3), 609.

El Mazlouzi, M., Morel, C., Robert, T., Chesseron, C., Salon, C., Cornu, J.-Y., & Mollier, A. 2022.The dynamics of phosphorus uptake and remobilization during the grain development period in durum wheat plants. *Plants*, **11**(8), 1006.

Elhaissoufi, W., Ghoulam, C., Barakat, A., Zeroual, Y., & Bargaz, A. 2022.Phosphate bacterial solubilization: A key rhizosphere driving force enabling higher P use efficiency and crop productivity. *Journal of Advanced Research*, **38**, 13-28.

Etesami, H., & Adl, S. M. 2020.Plant growth-promoting rhizobacteria (PGPR) and their action mechanisms in availability of nutrients to plants. *Phyto-Microbiome in stress regulation*, 147-203.

Etesami, H., Jeong, B. R., & Glick, B. R. 2021.Contribution of arbuscular mycorrhizal fungi, phosphate–solubilizing bacteria, and silicon to P uptake by plant. *Frontiers in Plant Science*, **12**, 699618.

Fetahi, T. 2019.Eutrophication of Ethiopian water bodies: a serious threat to water quality, biodiversity and public health. *African Journal of Aquatic Science*, **44**(4), 303-312.

Finore, I., Feola, A., Russo, L., Cattaneo, A., Di Donato, P., Nicolaus, B., Poli, A., & Romano, I. 2023.Thermophilic bacteria and their thermozymes in composting processes: a review. *Chemical and Biological Technologies in Agriculture*, **10**(1), 7.

Garraud, J., Plihon, H., Capiaux, H., Le Guern, C., Mench, M., & Lebeau, T. 2023.Drivers to improve metal (loid) phytoextraction with a focus on microbial degradation of dissolved organic matter in soils. *International Journal of Phytoremediation*, 1-19.

Griffiths, M., & York, L. M. 2020.Targeting root ion uptake kinetics to increase plant productivity and nutrient use efficiency. *Plant Physiology*, **182**(4), 1854-1868.

Gu, J., Guo, F., Lin, L., Zhang, J., Sun, W., Muhammad, R., Liang, H., Duan, D., Deng, X., & Lin, Z. 2023.Microbiological mechanism for "production while remediating" in Cd-contaminated paddy fields: A field experiment. *Science of the Total Environment*, **885**, 163896.

Guan, Z., Chen, T., Chen, D., Lu, Y., Han, Q., Li, N., Ma, W., Wang, J., Su, Y., & Li, J. 2023.Leaf Litter Breakdown and Soil Microbes in Catalpa bungei Plantations in Response to Various Fertilization Regimes. *Forests*, **14**(4), 699.

Harman, G., Khadka, R., Doni, F., & Uphoff, N. 2021.Benefits to plant health and productivity from enhancing plant microbial symbionts. *Frontiers in Plant Science*, **11**, 610065.

Havlin, J. L., & Schlegel, A. J. 2021.Review of phosphite as a plant nutrient and fungicide. *Soil systems*, **5**(3), 52.

Iqbal, B., Khan, I., Javed, Q., Alabbosh, K. F., Zhou, Z., & Rehman, A. 2023.The High Phosphorus Incorporation Promotes the Soil Enzymatic Activity, Nutritional Status, and Biomass of the Crop. *Polish Journal of Environmental Studies*, **32**(3).

Jha, U. C., Nayyar, H., Parida, S. K., Beena, R., Pang, J., & Siddique, K. H. 2023.Breeding and genomics approaches for improving phosphorus-use efficiency in grain legumes. *Environmental and Experimental Botany*, **205**, 105120.

Kalia, V. C., Gong, C., Patel, S. K., & Lee, J.-K. 2021.Regulation of plant mineral nutrition by signal molecules. *Microorganisms*, **9**(4), 774.

Khatri, S., Sazinas, P., Strube, M., Ding, L., Dubey, S., Shivay, Y., Sharma, S., & Jelsbak, L. 2023.Pseudomonas is a key player in conferring disease suppressiveness in organic farming. *Plant and Soil*, 1-20.

Khoshru, B., Nosratabad, A. F., Mitra, D., Chaithra, M., Danesh, Y. R., Boyno, G., Chattaraj, S., Priyadarshini, A., Anđelković, S., & Pellegrini, M. 2023.Rock Phosphate Solubilizing Potential of Soil Microorganisms: Advances in Sustainable Crop Production. *Bacteria*, **22**, 98-115.

Kollmen, J., & Strieth, D. 2022.The beneficial effects of cyanobacterial co-culture on plant growth. *Life*, **122**, 223.

Kumar, M., Giri, V. P., Pandey, S., Gupta, A., Patel, M. K., Bajpai, A. B., Jenkins, S., & Siddique, K. H. 2021.Plant-Growth-Promoting Rhizobacteria emerging as an effective bioinoculant to improve the growth, production, and stress tolerance of vegetable crops. *International Journal of Molecular Sciences*, *222*2, 12245.

Kumar, S., Kumar, S., & Mohapatra, T. 2021.Interaction between macro-and micro-nutrients in plants. *Frontiers in Plant Science*, **12**, 665583.

Kumari, S., Kumar, P., Kiran, S., Kumari, S., & Singh, A. 2023.Characterization of culture condition dependent, growth responses of phosphate solubilizing bacteria (Bacillus subtilis DR2) on plant growth promotion of Hordeum vulgare. *Vegetos*, 1-11.

Landa-Acuña, D., Toro, M., Santos-Mendoza, R., & Zúñiga-Dávila, D. 2023.Role of Rahnella aquatilis AZO16M2 in Phosphate Solubilization and Ex Vitro Acclimatization of Musa acuminata var. Valery. *Microorganisms*, **11**(6), 1596.

Li, M., & Cai, L. 2021.Biochar and arbuscular mycorrhizal fungi play different roles in enabling maize to uptake phosphorus. *Sustainability*, *13*(6), 3244.

Li, X., Zhang, Y., Kong, F.-L., Naz, M., Zhou, J.-Y., Qi, S.-S., Dai, Z.-C., & Du, D.-L. 2023.Invasive Plant Alternanthera philoxeroides Benefits More

Competition Advantage from Rhizosphere Bacteria Regardless of the Host Source. *Plants*, **12**(11), 2085.

Lu, J., Liu, S., Chen, W., & Meng, J. 2023.Study on the mechanism of biochar affecting the effectiveness of phosphate solubilizing bacteria. *World Journal of Microbiology and Biotechnology*, **39**(3), 87.

Ma, X., Li, X., & Ludewig, U. 2021.Arbuscular mycorrhizal colonization outcompetes root hairs in maize under low phosphorus availability. *Annals of botany*, **127**(1), 155-166.

Marschner, P., & Rengel, Z. 2023.Nutrient availability in soils. In *Marschner's Mineral Nutrition of Plants* (pp. 499-522.Elsevier).

Mayadunna, N., Karunarathna, S. C., Asad, S., Stephenson, S. L., Elgorban, A. M., Al-Rejaie, S., Kumla, J., Yapa, N., & Suwannarach, N. 2023.Isolation of Phosphate-Solubilizing Microorganisms and the Formulation of Biofertilizer for Sustainable Processing of Phosphate Rock. *Life*, **13**(3), 782.

Meena, M., Yadav, G., Sonigra, P., Nagda, A., Mehta, T., Swapnil, P., Harish, Marwal, A., & Kumar, S. 2023.Multifarious responses of forest soil microbial community toward climate change. *Microbial ecology*, **86**(1), 49-74.

Mitra, D., Mondal, R., Khoshru, B., Senapati, A., Radha, T., Mahakur, B., Uniyal, N., Myo, E. M., Boutaj, H., & SIERRA, B. E. G. 2022.Actinobacteria-enhanced plant growth, nutrient acquisition, and crop protection: Advances in soil, plant, and microbial multifactorial interactions. *Pedosphere*, **32**(1), 149-170.

Mo, X., Liu, G., Zhang, Z., Lu, X., Liang, C., & Tian, J. 2022.Mechanisms underlying soybean response to phosphorus deficiency through integration of omics analysis. *International Journal of Molecular Sciences*, **23**(9), 4592.

Mousavi, R., Rasouli-Sadaghiani, M., Sepehr, E., Barin, M., & Vetukuri, R. R. 2023.Improving Phosphorus Availability and Wheat Yield in Saline Soil of the Lake Urmia Basin through Enriched Biochar and Microbial Inoculation. *Agriculture*, **13**(4), 805.

Ndlovu, S., Suinyuy, T. N., Pérez-Fernández, M. A., & Magadlela, A. 2023.Encephalartos natalensis, Their Nutrient-Cycling Microbes and Enzymes: A Story of Successful Trade-Offs. *Plants*, **12**(5), 1034.

Netherway, T., Bengtsson, J., Krab, E. J., & Bahram, M. 2021.Biotic interactions with mycorrhizal systems as extended nutrient acquisition strategies shaping forest soil communities and functions. *Basic and Applied Ecology*, **50**, 25-42.

Niu, X.-y., Wang, S.-k., Zhou, J., Di, D.-l., Sun, P., & Huang, D.-z. 2021.Inoculation with indigenous rhizosphere microbes enhances aboveground accumulation of lead in Salix integra Thunb. by improving transport coefficients. *Frontiers in microbiology*, **12**, 686812.

Oyedoh, O. P., Yang, W., Dhanasekaran, D., Santoyo, G., Glick, B. R., & Babalola, O. O. 2023.Sustainable Agriculture: Rare-Actinomycetes to the Rescue. *Agronomy*, **13**(3), 666.

Pan, Y., Song, Y., Zhao, L., Chen, P., Bu, C., Liu, P., & Zhang, D. 2022.The genetic basis of phosphorus utilization efficiency in plants provide new insight into woody perennial plants improvement. *International Journal of Molecular Sciences*, **23**(4), 2353.

Patwardhan, S. B., Pandit, C., Pandit, S., Verma, D., Lahiri, D., Nag, M., Ray, R. R., Jha, P., & Prasad, R. 2022. Illuminating the signalomics of microbial biofilm on plant surfaces. *Biocatalysis and Agricultural Biotechnology*, 102537.

Pavlů, J., Novák, J., Koukalová, V., Luklová, M., Brzobohatý, B., & Černý, M. 2018.Cytokinin at the crossroads of abiotic stress signalling pathways. *International Journal of Molecular Sciences*, **19**(8), 2450.

Prasanna, R., Renuka, N., Nain, L., & Ramakrishnan, B. 2021.Natural and constructed cyanobacteria-based consortia for enhancing crop growth and soil fertility. *Role of Microbial Communities for Sustainability*, 333-362.

Püschel, D., Bitterlich, M., Rydlová, J., & Jansa, J. 2021.Drought accentuates the role of mycorrhiza in phosphorus uptake. *Soil Biology and Biochemistry*, **157**, 108243.

Qi, S., Wang, J., Wan, L., Dai, Z., da Silva Matos, D. M., Du, D., Egan, S., Bonser, S. P., Thomas, T., & Moles, A. T. 2022.Arbuscular mycorrhizal fungi contribute to phosphorous uptake and allocation strategies of Solidago canadensis in a phosphorous-deficient environment. *Frontiers in Plant Science*, **13**, 831654.

Rana, K. L., Kour, D., Yadav, A. N., Yadav, N., & Saxena, A. K. 2020.Agriculturally important microbial biofilms: biodiversity, ecological significances, and biotechnological applications. In *New and future developments in microbial biotechnology and bioengineering: Microbial biofilms* (pp. 221-265.Elsevier).

Raza, T., Qadir, M. F., Khan, K. S., Eash, N. S., Yousuf, M., Chatterjee, S., Manzoor, R., ur Rehman, S., & Oetting, J. N. 2023.Unrevealing the potential of microbes in decomposition of organic matter and release of carbon in the ecosystem. *Journal of environmental management*, **344**, 118529.

Resendiz-Nava, C. N., Alonso-Onofre, F., Silva-Rojas, H. V., Rebollar-Alviter, A., Rivera-Pastrana, D. M., Stasiewicz, M. J., Nava, G. M., & Mercado-Silva, E. M. 2023.Tomato Plant Microbiota under Conventional and Organic Fertilization Regimes in a Soilless Culture System. *Microorganisms*, **11**(7), 1633.

Romanelli, A., Soto, D. X., Matiatos, I., Martínez, D. E., & Esquius, S. 2020.A biological and nitrate isotopic assessment framework to understand eutrophication in aquatic ecosystems. *Science of the Total Environment*, **715**, 136909.

Sangwan, S., & Prasanna, R. 2022.Mycorrhizae helper bacteria: unlocking their potential as bioenhancers of plant–arbuscular mycorrhizal fungal associations. *Microbial ecology*, **84**(1), 1-10.

Sarmah, R., & Sarma, A. K. 2023.Phosphate solubilizing microorganisms: A review. *Communications in Soil Science and Plant Analysis*, **54**(10), 1306-1315.

Sen, A., Banerjee, S., Poddar, R., & Balo, S. 2023.Effectiveness of Three Organic Acids on Phosphorus Solubilization in Some Acid Soils of Eastern India. *Communications in Soil Science and Plant Analysis*, **54**(7), 992-1004.

Shaked, Y., de Beer, D., Wang, S., Zhang, F., Visser, A. N., Eichner, M., & Basu, S. 2023.Co-acquisition of mineral-bound iron and phosphorus by natural *Trichodesmium* colonies. *Limnology and Oceanography*, **68**(5), 1064-1077.

Singh, J., Isidra-Arellano, M. C., & Valdés-López, O. 2023.Harnessing the potential of symbiotic associations of plants in phosphate-deficient soil for sustainable agriculture. *Plant and Cell Physiology*, pcad059.

Singh, J. P., Ojinnaka, E. U., Krumins, J. A., & Goodey, N. M. 2019.Abiotic factors determine functional outcomes of microbial inoculation of soils from a metal contaminated brownfield. *Ecotoxicology and environmental safety*, **168**, 450-456.

Song, Q., Song, X., Deng, X., Luo, J., Wang, J., Min, K., & Song, R. 2021.Effects of plant growth promoting Rhizobacteria microbial on the growth, rhizosphere soil properties, and bacterial community of Pinus sylvestris var. mongolica seedlings. *Scandinavian Journal of Forest Research*, **36**(4), 249-262.

Stala, Ł., Ulatowska, J., & Polowczyk, I. 2023.Green polyampholytic ionic scavengers as an alternative to crude oil derived chelating resins for removal of toxic metals from aqueous solutions. *Journal of Environmental Chemical Engineering*, **11**(3), 109926.

Sulieman, S., & Mühling, K. H. 2021.Utilization of soil organic phosphorus as a strategic approach for sustainable agriculture. *Journal of Plant Nutrition and Soil Science*, **184**(3), 311-319.

Sun, X., Liu, F., Jiang, W., Zhang, P., Zhao, Z., Liu, X., Shi, Y., & Sun, Q. 2023.Talaromyces purpurogenus Isolated from Rhizosphere Soil of Maize Has Efficient Organic Phosphate-Mineralizing and Plant Growth-Promoting Abilities. *Sustainability*, **15**(7), 5961.

Tang, Z., Jiang, Y., Wang, C., Zhang, R., Guo, J., & Fang, F. 2023.New Insight into Phosphorus Release of Rhizosphere Soil in the Water Level Fluctuation Zone. *Sustainability*, **15**(8), 6635.

Tian, J., Ge, F., Zhang, D., Deng, S., & Liu, X. 2021.Roles of phosphate solubilizing microorganisms from managing soil phosphorus deficiency to mediating biogeochemical P cycle. *Biology*, **102**, 158.

Torres-Cuesta, D., Mora-Motta, D., Chavarro-Bermeo, J. P., Olaya-Montes, A., Vargas-Garcia, C., Bonilla, R., & Estrada-Bonilla, G. 2023.Phosphate-Solubilizing Bacteria with Low-Solubility Fertilizer Improve Soil P Availability and Yield of Kikuyu Grass. *Microorganisms*, **11**(7), 1748.

Tortosa, G., Mesa, S., Delgado, M. J., & Amaya-Gómez, C. V. 2023."Alperujo" Compost Improves Nodulation and Symbiotic Nitrogen Fixation of Soybean Inoculated with Bradyrhizobium diazoefficiens. *Nitrogen*, **42**, 223-230.

Trivedi, P., Leach, J. E., Tringe, S. G., Sa, T., & Singh, B. K. 2020.Plant–microbiome interactions: from community assembly to plant health. *Nature reviews microbiology*, **18**(11), 607-621.

Vera-Morales, M., López Medina, S. E., Naranjo-Morán, J., Quevedo, A., & Ratti, M. F. 2023.Nematophagous Fungi: A Review of Their Phosphorus Solubilization Potential. *Microorganisms*, **11**(1), 137.

Vidal, C., González, F., Santander, C., Pérez, R., Gallardo, V., Santos, C., Aponte, H., Ruiz, A., & Cornejo, P. 2022.Management of rhizosphere microbiota and plant production under drought stress: A comprehensive review. *Plants*, **11**(18), 2437.

Wahid, F., Fahad, S., Danish, S., Adnan, M., Yue, Z., Saud, S., Siddiqui, M. H., Brtnicky, M., Hammerschmiedt, T., & Datta, R. 2020.Sustainable management with mycorrhizae and phosphate solubilizing bacteria for enhanced phosphorus uptake in calcareous soils. *Agriculture*, **10**(8), 334.

Wang, J., Zhao, Y.-G., & Maqbool, F. 2021.Capability of Penicillium oxalicum y2 to release phosphate from different insoluble phosphorus sources and soil. *Folia Microbiologica*, **66**, 69-77.

Wang, Z., Leite, M. F., Jiang, M., Kuramae, E. E., & Fu, X. 2023.Responses of soil rare and abundant microorganisms to recurring biotic disturbances. *Soil Biology and Biochemistry*, **177**, 108913.

Wu, S., Shi, Z., Chen, X., Gao, J., & Wang, X. 2022.Arbuscular mycorrhizal fungi increase crop yields by improving biomass under rainfed condition: a meta-analysis. *PeerJ*, *10*, e12861.

Xie, K., Ren, Y., Chen, A., Yang, C., Zheng, Q., Chen, J., Wang, D., Li, Y., Hu, S., & Xu, G. 2022.Plant nitrogen nutrition: The roles of arbuscular mycorrhizal fungi. *Journal of Plant Physiology*, **269**, 153591.

Xiong, Q., Wang, S., Lu, X., Xu, Y., Zhang, L., Chen, X., Xu, G., Tian, D., Zhang, L., & Jing, J. 2023.The Effective Combination of Humic Acid Phosphate Fertilizer Regulating the Form Transformation of Phosphorus and the Chemical and Microbial Mechanism of Its Phosphorus Availability. *Agronomy*, **13**(6), 1581.

Xu, H., Lv, J., & Yu, C. 2023.Combined phosphate-solubilizing microorganisms jointly promote Pinus massoniana growth by modulating rhizosphere environment and key biological pathways in seedlings. *Industrial Crops and Products*, **191**, 116005.

Yadav, A., Boruah, J. L. H., Geed, S. R., Sharma, R. K., & Saikia, R. 2023.Occurrence, identification and characterization of diazotrophic bacteria from aerial roots of Rhynchostylis retusa (L.) Blume for plant growth-promoting activity. *Archives of Microbiology*, **205**(4), 131.

Yahya, M., Rasul, M., Sarwar, Y., Suleman, M., Tariq, M., Hussain, S. Z., Sajid, Z. I., Imran, A., Amin, I., & Reitz, T. 2022.Designing synergistic biostimulants formulation containing autochthonous phosphate-solubilizing bacteria for sustainable wheat production. *Frontiers in microbiology*, **13**, 889073.

Yan, Z., Liu, Z., Jia, Z., Song, C., Cao, X., & Zhou, Y. 2023.Metabolites of extracellular organic matter from Microcystis and Dolichospermum drive distinct modes of carbon, nitrogen, and phosphorus recycling. *Science of the Total Environment*, **865**, 161124.

Yang, J., Li, G., Sheng, Y., & Zhang, F. 2022.Response and contribution of bacterial and archaeal communities to eutrophication in urban river sediments. *Environmental Pollution*, **306**, 119397.

Zeng, Q., Ding, X., Wang, J., Han, X., Iqbal, H. M., & Bilal, M. 2022.Insight into soil nitrogen and phosphorus availability and agricultural sustainability by plant growth-promoting rhizobacteria. *Environmental Science and Pollution Research*, **29**(30), 45089-45106.

Zhang, D., Lyu, Y., Li, H., Tang, X., Hu, R., Rengel, Z., Zhang, F., Whalley, W. R., Davies, W. J., & Cahill Jr, J. F. 2020.Neighbouring plants modify maize root foraging for phosphorus: coupling nutrients and neighbours for improved nutrient-use efficiency. *New Phytologist*, **226**(1), 244-253.

Zhang, Y., Li, Y., Wang, S., Umbreen, S., & Zhou, C. 2021.Soil phosphorus fractionation and its association with soil phosphate-solubilizing bacteria in a chronosequence of vegetation restoration. *Ecological Engineering*, **164**, 106208.

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Review Article

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Environmental factors shaping alpine plant adaptations

Pallavi Sati[1*], Sachin Dimri[2], Vijay Laxmi Trivedi[1] and M C Nautiyal[1]
[1]High Altitude Plant Physiology Research Centre (HAPPRC), H.N.B. Garhwal University, Post Box: 14, Srinagar Garhwal 246174, Uttarakhand, India.
[2]Sai College of Pharmacy, 26, A- Rajpur road, Dehradun, Uttarakhand, India
**Corresponding author e-mail: pallavisati45@gmail.com*
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ABSTRACT
Alpine ecosystems are distinct and demanding settings that are defined by severe climatic extremes, such as frigid temperatures, intense radiation, and restricted nutrition supply. The adaptations of alpine plants are finely tuned responses to the unique environmental challenges they face. By delving into the intricate interplay between temperature, UV radiation, soil conditions, and precipitation patterns, are valuable insights into the resilience of alpine ecosystems. Such knowledge is not only crucial for advancing ecological understanding but also for informing conservation and management strategies in the era of global environmental change. We have covered all the abiotic factors affecting plant growth and development in alpine and subalpine area in this mini review. It will be beneficial for researchers, industrialists, ecologists and agriculturists.
Keywords: Alpine and Subalpine plants, Climate change, Conservation, Elevated CO_2, Temperature.

INTRODUCTION

Alpine environments are characterized by harsh and extreme conditions, including low temperatures, high radiation, strong winds, and rocky or nutrient-poor soils. These challenging conditions have led to the evolution of unique adaptations in alpine plants. Alpine plants often face freezing temperatures (García-Plazaola *et al*., 2015). They have developed strategies such as small, compact growth forms, hairy or waxy surfaces to reduce heat loss, and the ability to photosynthesize at low temperatures. At higher altitudes, oxygen levels decrease, and atmospheric pressure drops. Plants have adaptations like increased stomatal density to enhance gas exchange, altered respiratory pathways, and enhanced energy efficiency (Rawat *et al*., 2014). High-altitude environments receive intense UV radiation due to reduced atmospheric filtration. Alpine plants may have specialized pigments, such as anthocyanins, and reflective surfaces to protect against UV damage (Bashyal, 2023). Snow cover can provide insulation during winter. Some alpine plants may have adaptations to capture and retain snow, creating a microenvironment that buffers against temperature extremes. Wind can be strong in alpine zones, and plants often adopt low, cushion-like growth forms to minimize exposure and reduce desiccation. Alpine plants face a short growing season. Many species have adapted by flowering and producing seeds early in the season to ensure reproductive success before the onset of harsh conditions (Linu *et al.* (2015). Alpine soils are often nutrient poor. Plants may develop extensive root systems, mycorrhizal associations, or adaptations for nutrient uptake efficiency to thrive in such conditions. Snow cover can provide insulation during winter. Some alpine plants may have adaptations to capture and retain snow, creating a microenvironment that buffers against temperature extremes. Human activities, such as tourism and climate change, can impact alpine ecosystems. Increased foot traffic can disturb fragile vegetation, and climate change may alter temperature and precipitation patterns, affecting plant distribution (Rawat *et al*., 2014). Limited vegetation and herbivore pressure can lead to the evolution of chemical defenses, such as secondary metabolites, to deter herbivores. We have tried to compile a short report on how environmental factors affecting the plants at higher elevation. Understanding how alpine plants adapt to extreme conditions helps in developing strategies for their conservation. As alpine ecosystems are particularly vulnerable to climate change and human disturbances, conservation efforts can benefit from insights into these adaptations (Rathore *et al*., 2018).

Different environmental factors and their effect

Nutrients - Previous research have shown that the development of alpine plant species is greatly influenced by the availability of nutrients. Plants at higher altitudes encounter limited nutrient availability, which may adversely impact their growth and development. *Aconitum carmichaeli* exhibited enhanced growth when

treated with NPK, and a reduced biomass was found when exposed to low nutrient concentrations (Hou *et al.* 2006). In another study, plant height, tuber length, leaf number, aconitine and pseudoaconitine content increased when grown under nutrient rich environment in *Aconitum heterophyllum* and *Aconitum balfourii* (Bahuguna *et al*., 2013). *Rheum tanguticum* also affected by different level of nutrients (Shen *et al.* 2023). Root length, root fresh weigh and root diameter increased when fertilized with phosphorus and potassium. Multiple studies have shown that plants use various adaption mechanisms to deal with limited nutrition availability in alpine regions such as *Rhododendron anthopogon* (Rathore *et al.* 2018), *Saxifraga hostii* (Sedej *et al.* 2020), *Taxus wallichiana* (Adhikari *et al.* 2022) and *Aconitum naviculare* (Bashyal, 2023).

UV-radiation

In alpine regions, plants are exposed to elevated levels of ultraviolet (UV) radiation due to factors such as high altitude, clear skies, and reduced atmospheric filtration. UV radiation consists of UVA (320–400 nm), UVB (280–320 nm), and UVC (100–280 nm), with UVC mostly filtered by the Earth's atmosphere. According to Sedej *et al.* (2020), *Saxifraga hostii* exhibited high photochemical efficiency of photosystem II and stomatal conductance under near ambient UV radiation. However, leaf tissue thicknesses were not affected by different treatments of UV radiation. Their study concluded that, *S. hostii* leaves showed high absorption in the UV spectrum at higher altitudes, as shown by their optical properties. In *Kobresia humilis* enhanced UV-B radiation resulted in a significant increase of both leaf area and fresh weight. On the other hand, the enhanced UV-B radiation was associated with 2–3 days earlier flowering and a larger number of flowers per spikelet (Shi *et al*., 2022).

Elevated Carbon dioxide

Prior report demonstrated the effect of elevated CO_2 concentration on the growth, productivity, physiology, and various biochemical parameters of four alpine treelined herbaceous species, viz. *Acomastylis elata, Anaphalis nepalensis, Bistorta macrophylla,* and *Trillium govanianum* (Chandra *et al*., 2023). Their study revealed that, *Acomastylis elata* and *Anaphalis nepalensis* showed positive response to elevated CO_2 by increasing net photosynthesis, growth and productivity. On the other hand, *Bistorta macrophylla*, and *Trillium govanianum* decrease in net photosynthetic rate. The long-term effects of elevated CO_2 on *Picea abies, Pinus sylvestris* and *Betula pubescens* Ehrh. were examined in open-top chambers after a 4-year-long experiment. The *Picea abies* and *Betula pubescens* reduced biomass when exposed to elevated CO_2, while *Pinus sylvestris* increased biomass under elevate CO_2 (Vanhatalo *et al*., 2003). However, no effect observed in sever plant species such as *Vaccinium gaultherioides* and *Empetrum hermaphroditum* (Dawes *et al*., 2011). In Larix decidua Mill. and *Pinus mugo* net photosynthetic rate and stomatal conductance increased when exposed to elevated CO_2 while no changes observed in transpiration rate (Streit *et al*., 2014).

Temperature

Temperature plays a crucial role in the growth and metabolism of alpine plants, which are adapted to survive in harsh, cold environments at high altitudes. The impact of temperature on alpine plant physiology can be observed at various levels, including growth, photosynthesis, respiration, and overall metabolic processes. According to results from the study by Ma *et al.* (2015), *Potentilla saundersiana* modulates the root architecture and leaf phenotype to enhance adaptation to alpine environmental stress developed by low temperature and UV radiation. However no significant effects, also observed in alpine plants (*Soldanella alpina and Ranunculus glacialis*) when treated by low temperature (Sterb *et al*., 2003). Alpine regions typically have a short growing season due to low temperatures. Additionally, such climatic conditions can inhibit the growth of the alpine plant species. As earlier reported that increased temperature promoted the plant growth and development in *Ranunculus glacialis, Tussilago farfara, Rumex alpinus, Poa alpina* (Nagelmüller *et al*., 2017). Jeong *et al.* (2021) found that elevated temperatures may impact the growth and development of alpine plants when there is an adequate supply of nutrients. Their investigation revealed the adaptive reactions of *Primula farinosa* during its initial developmental phase in response to temperature. The findings indicated that plants had reduced survival rates but increased rosette size and leaf count in response to elevated temperatures. Another study revealed that, Temperature and precipitation are the main deterministic factors in species biomass change in *Betula* spp. and *Abies* spp (Usoltsev *et al*., 2022). Another study revealed that, net photosynthetic rate increased with decreasing temperature in *Abies koreana* (Woo *et al*., 2008) and decreased in *Abies faxoniana* (Yu *et al*., 2019). Prior studies also found that increased temperature had a substantial positive effect on the development of slow-growing alpine plant species (*Plantago euryphylla*) by increasing net photosynthesis and respiration rate (Atkin *et al*., 2006). However negative reports are also available in literature. Warmer temperatures during the growing season can extend the time available for alpine plants to complete their life cycles, including germination, flowering, and seed production. Rising global temperatures are inducing upward altitudinal migrations, altering the traditional distribution patterns of alpine vegetation (Li *et al*., 2013; Mietkiewicz *et al*., 2017). The tree line, indicative of the uppermost limit where trees can grow, is ascending, compelling alpine plant species to relocate to higher elevations.

Water availability

At higher elevations, water availability can be limited due to factors such as lower temperatures, reduced precipitation, and increased evaporation rates. Alpine plants often need to cope with scarcity by developing specialized adaptations to conserve water. Alpine plants

have evolved various adaptations to cope with limited water availability. These adaptations may include reduced leaf surface area, deep root systems, and the ability to store water in specialized tissues. The accumulation of secondary metabolites is a common response in plants when they are subjected to drought. Phenolic compounds, including flavonoids and other polyphenols, act as antioxidants. They help protect plants from oxidative stress caused by reactive oxygen species (ROS) produced during drought conditions. Antioxidants neutralize ROS, preventing cellular damage. Prior research has shown the impact of extreme drought on plant diversity in the elevated areas. For example, *Artemisia brevifolia* showed variation in secondary metabolites along with altitudinal gradient in the Ladakh region (low water availability) of the Western Himalayas, which are often known as "cold desert." GCMS analyses showed that the total number of volatile compounds in *A. brevifolia* increased with elevation. HPLC analyses showed no effect of elevation on the total number of phenolic compounds detected in both young and mature leaves. However, the concentration of the majority of phenolic compounds decreased with elevation (Nataraj *et al*., 2022). On the other hand, another study from the same region demonstrated that, metabolome analysis showed decreasing concentration of bioactive phenolics with the increase in altitude in *A. brevifolia* (Hussain *et al*., 2023). The antioxidant activity of the sample extracts from low-altitude sites showed a higher inhibition percentage compared to high-altitude sites. Phenological changes also reported in some plants like *Campanula scheuchzeri* Vil, *Ranunculus montanus* Willd by Cornelius *et al.* (2013), who revealed that, anther dehydration induced by drought stress in alpine and arctic regions. Alpine plants may have these adaptations to enhance water use efficiency, as water availability can be limited in these environments. Reduction in biomass, total leaf count, leaf size and specific leaf area, increase in root biomass observed in *Aciphylla glacialis*, *Oreomyrrhis eriopoda* and *Wahlenbergia ceracea* with increasing elevation (Geange *et al*., 2017).

Wind speed

Wind speed can significantly impact plants in alpine regions, where environmental conditions are often harsh. Wind can exacerbate temperature extremes in alpine regions (Sekar *et al*., 2023). During winter, strong winds can enhance the chilling effect on plants, making them more susceptible to frost damage. In summer, rapid air movement can contribute to cooling, affecting the overall temperature conditions (Crabtree *et al*., 2010). High wind speeds can hinder the process of pollination, which is crucial for the reproduction of many plant species. Wind may disrupt the flight of pollinators and scatter pollen away from its intended destination (Holtmeier *et al*., 2010). In response to the challenging conditions, some alpine plants may adopt a dwarf or prostrate growth form to reduce exposure to wind. This adaptation helps them conserve energy and resist mechanical damage Heydel *et al.* (2014).

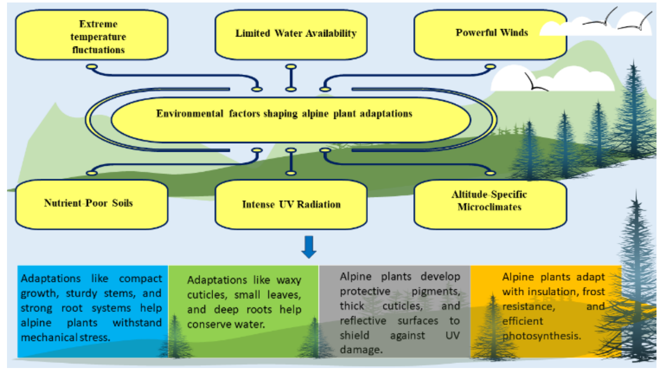

Figure 1. Environmental factors mediated response of alpine and subalpine plant species

Future prospects

Gaining insight into the mechanisms by which alpine plants acclimatize to harsh environments is crucial in formulating effective approaches for their preservation. Given the susceptibility of alpine ecosystems to climate change and human stressors, conservation initiatives can gain valuable knowledge from studying these adaptations. Alpine habitats are distinct and have a vital function in worldwide biodiversity (Sekar *et al*., 2023). Examining plant adaptations offers useful insights into the complex interconnections of plants, microbes, and other creatures in these habitats. Alpine habitats serve as highly responsive markers of climate change. Through the examination of plant adaptations, scientists are able to see the reactions of these ecosystems to changing climatic circumstances, therefore yielding crucial data for climate change studies and forecasts (Cornelius *et al*., 2013). The adaptations exhibited by alpine plants have the potential to serve as a source of inspiration for the advancement of novel technologies and materials. For instance, comprehending the mechanisms by which plants shield themselves from UV radiation might provide valuable insights for developing compounds aimed at sun protection across many sectors. Alpine plants exhibit some adaptations, such as the ability to withstand drought and efficiently use nutrients, which might potentially be beneficial in agricultural practices. The knowledge acquired from these modifications may be utilized to cultivate crops that exhibit greater resilience in the face of demanding environmental circumstances (Jeong *et al*., 2021). Exploring the adaptations of alpine plants offers educational prospects for students and researchers, cultivating a more profound comprehension of plant ecology, evolution, and the interdependence of ecosystems. This understanding enhances the wider domain of biology and environmental science (Nagelmüller *et al*., 2017). Alpine plants frequently generate bioactive chemicals as a component of their adaptations to harsh circumstances. These chemicals have potential uses in the fields of pharmaceuticals and industry, and investigating these

modifications can result in the identification of innovative bioactive molecules (Li *et al*., 2022). Alpine ecosystems have a crucial role in providing vital ecosystem services such as water control, carbon sequestration, and habitat for diverse species. Gaining knowledge about the adjustments of alpine plants aids in the evaluation and sustainable management of these functions (Vanhatalo *et al*., 2003).

Table 1. Different factors affecting plants from alpine and subalpine zone and plant response

Plant Name	**Factors affecting**	**Plant response**	**Reference**
Abies faxoniana	Elevated temperature	Promotion of plant growth by increasing net photosynthesis and biomass	Woo *et al*., 2009
Abies faxoniana	Elevated temperature	Promotion of plant growth by increasing net photosynthesis and biomass	Yu *et al*., 2020
Abies koreana	Low temperature	Increase net photosynthesis	Woo *et al*., 2008
Abies spp.	Elevated temperature	Biomass production	Usoltsev *et al*., 2023
Aciphylla glacialis	Water scarcity	Reduction in biomass,total leaf count, leaf size and specific leaf area, increase in root biomass.	Geange *et al*., 2017
Acomastylis elata	Elevated CO_2	Increase in net assimilation rate, growth and productivite	Chandra *et al*., 2023
Aconitum heterophyllum	Elevated CO_2	Increase in total soluble sugar, proline and lipid peroxidation and decrease in starch content, secondary metabolites and leaf nitrogen content	Chandra *et al*., 2023
Aconitum balfourii	Elevated CO_2	Increase in total soluble sugar, proline and lipid peroxidation and decrease in starch content, secondary metabolites and leaf nitrogen content	Chandra *et al*., 2022
Anaphalis nepalensis	Elevated CO_2	Increase in net assimilation rate, growth and productivity	Chandra *et al*., 2024
Androsace tapet	Low temperature and precipitation	Habitat shift	Li *et al*., 2013
Artemisia brevifolia	Drought	Increase in total number of volatile compounds	Nataraj *et al*., 2022
Artemisia brevifolia	Drought	Decreasing concentration of bioactive phenolics	Hussain *et al*., 2023
Astragalus laxmannii	Elevated temperature	Vegetative and reproductive growth increased significantly	Li *et al*., 2022
Betula pubescens	Elevated CO_2	Biomass decreased	Vanhatalo *et al*., 2003
Betula spp.	Elevated temperature	Biomass production	Usoltsev *et al*., 2022
Bistorta macrophylla	Elevated CO_2	Decrease in net photosynthesis	Chandra *et al*., 2025
Campanula scheuchzeri Vil	Drought	Anther dehydration	Cornelius *et al*., 2013
Empetrum hermaphroditum)	Elevated CO_2	No effect	Dawes *et al*., 2011
Kobresia humilis	UV- radiation	Increase in leaf area and fresh weight, early flowering	Shi *et al*., 2022
Kobresia humilis	Elevated temperature	Vegetative and reproductive growth increased significantly	Li *et al*., 2022
Larix decidua	Drought	Reduced plant water availability and transpiration rate	Leo *et al*., 2014
Larix decidua Mill.	Elevated CO_2	Increase in photosynthesis and stomatal conductance, no change in transpiration rate	Streit *et al*., 2014
Oreomyrrhis eriopoda	Water scarcity	Reduction in biomass, leaf count, leaf size and specific leaf area, increase in root biomass.	Geange *et al*., 2017
Picea abies	Drought	Reduced plant water availability and transpiration rate	Leo *et al*., 2014
Picea abies	Elevated CO_2	Biomass decreased	Vanhatalo *et al*., 2003
Picea purpurea	Elevated temperature	Promotion of plant growth by increasing net photosynthesis and biomass	Yu *et al*., 2019
Pinetum typicum	Drought	Reduced plant water availability and transpiration rate	Leo *et al*., 2014

Pinus mugo	Elevated CO_2	Increase in photosynthesis and stomatal conductance, no change in transpiration rate	Streit *et al*., 2014
Pinus sylvestris	Drought	Reduced plant water availability and transpiration rate	Leo *et al*., 2014
Pinus sylvestris	Elevated CO_2	Biomass production	Vanhatalo *et al*., 2003
Plantago euryphylla	High temperature	Increase in net photosynthesis and respiration rate	Atkin *et al*., 2006
Poa alpina	Low temperature	Inhibition of cell differentiation	Nagelmüller *et al*., 2020
Primula farinosa	High temperature	Reduction in survival rates but increased rosette size and leaf count	Jeong *et al*., 2021
Ranunculus glacialis	Low temperature	Inhibition of root growth	Nagelmüller *et al*., 2019
Ranunculus glacialis	Low temperature	No changes observed in xanthophyll cycle compounds	Streb *et al*., 2003
Ranunculus montanus Willd	Drought	Anther dehydration	Cornelius *et al*., 2013
Rumex alpinus	Low temperature	Changes in root architecture	Nagelmüller *et al*., 2017
Saxifraga hostii	UV- radiation	high absorption in the UV spectrum at higher altitudes	Sedej *et al*., 2020
Soldanella alpina	Low temperature	No change in antioxidant compounds	Streb *et al*., 2003
Stipa purpurea	Elevated temperature	Vegetative growth increased significantly	Streit *et al*., 2014
Trillium govanianum	Elevated CO_2	Decrease in net photosynthesis	Chandra *et al*., 2026
Tussilago farfara	Low temperature	Inhibition of root growth	Nagelmüller *et al*., 2018
Vaccinium gaultherioides	Elevated CO_2	No effect	Dawes *et al*., 2011
Vaccinium myrtillus	Elevated CO_2	Increase in Biomass and leaf nitrogen content	Dawes *et al*., 2011
Wahlenbergia ceracea	Water scarcity	Reduction in biomass, total leaf count, leaf size and specific leaf area, increase in root biomass.	Geange *et al*., 2017

CONCLUSION

The study of alpine plant adaptations is vital for biodiversity conservation, climate change research, and technological innovation. Alpine ecosystems, with their extreme conditions, serve as valuable indicators of climate change impacts. Understanding plant adaptations provides insights into ecosystem resilience and informs conservation strategies. Moreover, these adaptations may inspire bioinspired technologies and materials for various applications. The knowledge gained contributes to agricultural resilience, sustainable tourism, and educational advancements. Alpine plants also offer potential pharmaceutical and industrial applications through the discovery of bioactive compounds. Overall, delving into alpine plant adaptations is not only crucial for preserving these unique ecosystems but also enhances our understanding of plant ecology and evolution, with far-reaching implications for diverse scientific disciplines and practical applications in a rapidly changing world.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Adhikari, P., Joshi, K., Singh, M., & Pandey, A. 2022. Influence of altitude on secondary metabolites, antioxidants, and antimicrobial activities of Himalayan yew (*Taxus wallichiana*. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, **156**(1): 187-195.

Ahmad, K. S., Hameed, M., Fatima, S., Ashraf, M., Ahmad, F., and Naseer, M. 2016. Morpho-anatomical and physiological adaptations to high altitude in some Avenue grasses from Neelum Valley, Western Himalayan Kashmir. *Acta Physiol. Plantar*. **38**:93. doi: 10.1007/s11738-016-2114-x.

Amaral, J., Lobo, A. K., & Carmo-Silva, E. 2024. Regulation of Rubisco activity in crops. *New Phytologist*, **241**(1): 35-51.

Atkin, O. K., Scheurwater, I., & Pons, T. L. 2006. High thermal acclimation potential of both photosynthesis and respiration in two lowland Plantago species in contrast to an alpine congeneric. *Global Change Biology*, **12**(3): 500-515.

Bahuguna, R., Prakash, V., & Bisht, H. 2013. Quantitative enhancement of active content and biomass of two aconitum species through suitable cultivation technology. *International Journal of Conservation Science*, **4**(1).

Bano, A., and Fatima, M. 2009. Salt tolerance in *Zea mays* (L.) following inoculation with Rhizobium and Pseudomonas. *Biol. Fertil. Soils* **45**: 405–413. doi: 10.1007/s00374-008-0344-9.

Bashyal, S. 2023. *Plant functional traits of Aconitum Spicatum and Aconitum naviculare along the elevation gradients in central Nepal* (Doctoral dissertation, Department of Botany.

Bharali, S., Paul, A., Khan, M. L., & Singha, L. B. 2012. Survival and growth of seedlings of two Rhododendron tree species along an altitudinal gradient in a temperate broad-leaved forest of Arunachal Pradesh, India. *International Journal of Plant Research*, **2**(1): 39-46.

Chandra, S., & Lata, H. 2022. Effect of Altitude on Biochemical and Photosynthetic Characteristics of Aconitum balfourii and Podophyllum hexandrum: High Value Endangered Medicinal Herbs from Himalayas. *International Journal of Tropical Agriculture*, **40**(3-4): 195-203.

Chandra, S., Chandola, V., Singh, A., Singh, C. P., & Nautiyal, M. C. 2023. Responses of Herbaceous Species of Alpine Treeline to Elevated CO2. In *Ecology of Himalayan Treeline Ecotone* (pp. 439-453. Singapore: Springer Nature Singapore.

Cui, G., Li, B., He, W., Yin, X., Liu, S., Lian, L., & Zhang, P. 2018. Physiological analysis of the effect of altitudinal gradients on Leymus secalinus on the Qinghai-Tibetan Plateau. *PloS one*, **13**(9): e0202881.

Deswal, R., & Sharma, B. 2014. Antifreeze proteins in plants: an overview with an insight into the detection techniques including nanobiotechnology. *Journal of Proteins & Proteomics*, **52**.

Gao, X., Zhang, Y., He, Z., & Fu, X. 2017. Gibberellins. [Li, JY, Li, CY, & Smith, SM (eds.)] Hormone Metabolism & Signaling in Plants. **4**:107–160.

García-Plazaola, J. I., Rojas, R., Christie, D. A., & Coopman, R. E. 2015. Photosynthetic responses of trees in high-elevation forests: comparing evergreen species along an elevation gradient in the Central Andes. *AoB Plants*, **7**, plv058.

Geange, S. R., Briceño, V. F., Aitken, N. C., Ramirez-Valiente, J. A., Holloway-Phillips, M. M., & Nicotra, A. B. 2017. Phenotypic plasticity and water availability: responses of alpine herb species along an elevation gradient. *Climate Change Responses*, **4**(1): 1-12.

Gruwez, R., De Frenne, P., De Schrijver, A., Leroux, O., Vangansbeke, P., & Verheyen, K. 2014. Negative effects of temperature and atmospheric depositions on the seed viability of common juniper (Juniperus communis. *Annals of Botany*, **113**(3): 489-500.

Guo, Q. Q., Li, H. E., & Zhang, W. H. 2016. Variations in leaf functional traits and physiological characteristics of Abies georgei var. smithii along the altitude gradient in the Southeastern Tibetan Plateau. *Journal of mountain Science*, **13:**1818-1828.

He, M., Yang, B., & Bräuning, A. 2013. Tree growth–climate relationships of Juniperus tibetica along an altitudinal gradient on the southern Tibetan Plateau. *Trees*, **27:** 429-439.

Hou, D., Shu, G., & Ren, Z. 2006. Effect of nitrogen, phosphorus, and potassium on several nitrogen metabolism enzymes of Aconitum carmichaeli Dexb. (Ranunculaceae. *Southwest China Journal of Agricultural Sciences*, *19*(5): 857-862.

Jamloki, A., Singh, A., Chandra, S., Shukla, V., Nautiyal, M. C., & Malik, Z. A. 2023. Population structure, regeneration potential and leaf morphological traits of *Rhododendron campanulatum* D. Don along an altitudinal gradient in Western Himalaya. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, **157**(1): 159-174.

Jiang, Y., CHENG1ϕ, X. I. A. O. M. A. O., Zi, H., & Huang, X. 2021. Physiological and ecological responses of an alpine plant picea likiangensis at different altitudinal gradient Sn. *Pak. J. Bot*, **53**(6): 2233-2240.

Kammer PM, Steiner JS, Schöb C. 2015. *Arabis alpina* and *Arabidopsis thaliana* have different stomatal development strategies in response to high altitude pressure conditions. *Alp Bot*. **1252**:1–12.

Kessler, M., Siorak, Y., Wunderlich, M., & Wegner, C. 2007. Patterns of morphological leaf traits among pteridophytes along humidity and temperature gradients in the Bolivian Andes. *Functional Plant Biology*, **34**(11): 963-971.

Kumari, M., & Kumar, R. 2024. Functional trait correlation network and proteomic analysis reveal multifactorial adaptation mechanisms to a climatic gradient associated with high altitude in the Himalayan region. *Plant, Cell & Environment*.

Landi, M., Tattini, M., & Gould, K. S. 2015. Multiple functional roles of anthocyanins in plant-environment interactions. *Environmental and Experimental Botany*, **119**, 4-17.

Li, R., Luo, T., Tang, Y., Du, M., & Zhang, X. 2013. The altitudinal distribution center of a widespread cushion species is related to an optimum combination of temperature and precipitation in the central Tibetan Plateau. *Journal of Arid Environments*, **88**: 70-77.

Li, X., Yang, Y., Ma, L., Sun, X., Yang, S., Kong, X., ... & Yang, Y. 2014. Comparative proteomics analyses of Kobresia pygmaea adaptation to environment along an elevational gradient on the central Tibetan Plateau. *PloS one*, **9**(6): e98410.

Liu, W., Zheng, L., & Qi, D. 2020. Variation in leaf traits at different altitudes reflects the adaptive strategy of plants to environmental changes. *Ecology and Evolution*, **10**(15): 8166-8175.

Ma L, Yang L, Zhao J, Wei J, Kong X, Wang C, Zhang X, Yang Y, Hu X. 2015. Comparative proteomic analysis reveals the role of hydrogen sulfide in the adaptation of the alpine plant Lamiophlomis rotata to altitude gradient in the northern Tibetan plateau. *Planta*. **241**(4):887–906.

Magaña Ugarte, R., Escudero, A., & Gavilán, R. G. 2019. Metabolic and physiological responses of Mediterranean high‐mountain and alpine plants to combined abiotic stresses. *Physiologia plantarum*, **165***(*2): 403-412.

Mangral, Z. A., Islam, S. U., Tariq, L., Kaur, S., Ahmad, R., Malik, A. H., ... & Dar, T. U. H. 2023. Altitudinal gradient drives significant changes in soil physico-chemical and eco-physiological properties of Rhododendron anthopogon: a case study from Himalaya. *Frontiers in Forests and Global Change*, ***6***, 1181299.

Maxime, C., & Hendrik, D. 2011. Effects of climate on diameter growth of co-occurring Fagus sylvatica and Abies alba along an altitudinal gradient. *Trees*, **25***(*2): 265-276.

Musarella, C. M., Brullo, S., & Del Galdo, G. G. 2020. Contribution to the orophilous cushion-like vegetation of central-southern and insular Greece. *Plants*, b(12): 1678.

Nataraj, N., Hussain, M., Ibrahim, M., Hausmann, A. E., Rao, S., Kaur, S., ... & Olsson, S. B. 2022. Effect of altitude on volatile organic and phenolic compounds of Artemisia brevifolia Wall ex Dc. from the Western Himalayas. *Frontiers in Ecology and Evolution*, **10**, 864728.

Noctor, G., Mhamdi, A., & Foyer, C. H. 2014. The roles of reactive oxygen metabolism in drought: not so cut and dried. *Plant physiology*, **164**(4): 1636-1648.

Ortiz, P. L., Arista, M., & Talavera, S. 2002. Sex ratio and reproductive effort in the dioecious Juniperus communis subsp. alpina (Suter) Čelak. (Cupressaceae) along an altitudinal gradient. *Annals of botany*, ***89****(*2): 205-211.

Rahman, I. U., Afzal, A., Iqbal, Z., Hart, R., Abd_Allah, E. F., Alqarawi, A. A., ... & Bussmann, R. W. 2020. Response of plant physiological attributes to altitudinal gradient: Plant adaptation to temperature variation in the Himalayan region. *Science of The Total Environment*, **706**, 135714.

Rahman, I. U., Hart, R., Afzal, A., Iqbal, Z., Alqarawi, A. A., Abd_Allah, E. F., ... & Calixto, E. S. 2019. Ecophysiological plasticity and cold stress adaptation in Himalayan alpine herbs: bistorta affinis and Sibbaldia procumbens. *Plants*, **8**(10): 378.

Rathore, N., Thakur, D., & Chawla, A. 2018. Seasonal variations coupled with elevation gradient drives significant changes in eco-physiological and biogeochemical traits of a high-altitude evergreen broadleaf shrub, Rhododendron anthopogon. *Plant Physiology and Biochemistry*, **132**, 708-719.

Rawat, J. M., Rawat, B., Mishra, S., Negi, R., Mishra, S. N., Chandra, A., & Nautiyal, S. 2014. Altitudinal and seasonal variation in bioactive compound aconitine in Aconitum violaceum, a threatened medicinal plant of Indian Himalayan region. *International Journal of Advanced Research*, **2**, 981-988.

Sedej, T. T., Erznožnik, T., & Rovtar, J. 2020. Effect of UV radiation and altitude characteristics on the functional traits and leaf optical properties in Saxifraga hostii at the alpine and montane sites in the Slovenian Alps. *Photochemical & Photobiological Sciences*, **19**, 180-192.

Senica, M., Stampar, F., Veberic, R., & Mikulic‐Petkovsek, M. 2017. The higher the better? Differences in phenolics and cyanogenic glycosides in Sambucus nigra leaves, flowers and berries from different altitudes. *Journal of the Science of Food and Agriculture*, **97**(8): 2623-2632.

Shen, N., Xu, W., Guo, F., Cui, Y., Chen, Y., & Su, X. 2023. Effect of fertilizer and harvesting stage on growth and bioactive compounds content of Rheum tanguticum. *Journal of Plant Nutrition*, *46*(18): 4462-4476.

Shi, S., Shi, R., Li, T., & Zhou, D. 2022. UV-B Radiation Effects on the Alpine Plant Kobresia humilis in a Qinghai-Tib*et al*pine Meadow. *Plants*, **112**(2): 3102.

Shi, Z., Liu, S., Liu, X., & Centritto, M. 2006. Altitudinal variation in photosynthetic capacity, diffusional conductance and δ13C of butterfly bush (Buddleja davidii) plants growing at high elevations. *Physiologia Plantarum*, **128**(4): 722-731.

Stiles, E. A., Cech, N. B., Dee, S. M., & Lacey, E. P. 2007. Temperature‐sensitive anthocyanin production in flowers of Plantago lanceolata. *Physiologia Plantarum*, **129**(4): 756-765.

Streb, P., & Cornic, G. 2011. Photosynthesis and antioxidative protection in alpine herbs. In *Plants in Alpine Regions: Cell Physiology of Adaption and Survival Strategies* (pp. 75-97. Vienna: Springer Vienna.

Streb, P., Aubert, S., Gout, E., & Bligny, R. 2003. Reversibility of cold‐and light‐stress tolerance and accompanying changes of metabolite and antioxidant levels in the two high mountain plant species Soldanella alpina and Ranunculus glacialis. *Journal of experimental botany*, **54**(381): 405-418.

Streit, K., Siegwolf, R. T., Hagedorn, F., Schaub, M., & Buchmann, N. 2014. Lack of photosynthetic or stomatal regulation after 9 years of elevated [CO2] and 4 years of soil warming in two conifer

species at the alpine tree line. *Plant, cell & environment*, **37**(2): 315-326.

Thapliyal, J., & Shukla, V. 2022. The elevational effect on soil parameters and biochemical constituents of Rheum emodi Wall. exMeisn: an important medicinal plant of Garhwal Himalaya.

Wang, Y. Y., Qi, D. H., Liu, W. S., & Liang, W. B. 2016. Comparison on leaf phenotypic and anatomical structures of Polygonum paleaceum along altitudinal gradients at Yulong Mountains. *Acta Botanica Boreali-Occidentalia Sinica*, **36**, 70–77.

Wani, Z. A., Negi, V. S., Bhat, J. A., Satish, K. V., Kumar, A., Khan, S., *et al.* 2023. Elevation, aspect, and habitat heterogeneity determine plant diversity and compositional patterns in the Kashmir Himalaya. Front. For. Glob. Change **6**:1019277. doi: 10.3389/ffgc.2023.1019277.

Ye, L. J., Möller, M., Luo, Y. H., Zou, J. Y., Zheng, W., Liu, J., ... & Gao, L. M. 2023. Variation in gene expression along an elevation gradient of Rhododendron sanguineum var. haemaleum assessed in a comparative transcriptomic analysis. *Frontiers in Plant Science*, **14**, 1133065.

Zhai, B., Hu, Z., Sun, S., Tang, Z., & Wang, G. 2024. Characteristics of photosynthetic rates in different vegetation types at high-altitude in mountainous regions. *Science of The Total Environment*, **907**, 168071.

Zhang, C. Y., Wang, Y., Li, M. S., Xu, M. Z., & Liu, X. H. 2014. Comparative analysis of anatomical structure of Rhododendron chrysanthum leaves at different altitudes in Changbai Mountain area. *Journal of Agricultural Science Yanbian University*, **36**, 39–43.

Zhang, Y., Ai, J., Sun, Q., Li, Z., Hou, L., Song, L., *et al.* 2021. Soil organic carbon and total nitrogen stocks as affected by vegetation types and altitude across the mountainous regions in the Yunnan Province, south-western China. *Catena* **196**:104872. doi: 10.1016/j.catena.2020.104872.

Zhao, Y., Xu, F., Liu, J., Guan, F., Quan, H., & Meng, F. 2019. The adaptation strategies of Herpetospermum pedunculosum (Ser.) Baill at altitude gradient of the Tibetan plateau by physiological and metabolomic methods. *BMC genomics*, **20**, 1-15.

Zoratti, L., Jaakola, L., Häggman, H., & Giongo, L. 2015. Anthocyanin profile in berries of wild and cultivated Vaccinium spp. along altitudinal gradients in the Alps. *Journal of Agricultural and Food Chemistry*, **63**(39): 8641-8650.

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Research Article

OPEN ACCESS

New State Records of Three Plume T-Moths (Pterophoridae) at Paradip, Odisha, East India

Suruliyandi Vijayan
National Centre for Sustainable Coastal Management (NCSCM), Ministry of Environment, Forest and Climate Change, Anna Uni versity Campus, Chennai, Tamil Nadu, India
**Corresponding author e-mail: svvijay89@gmail.com*
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ABSTRACT
In the present study, *Cnaemidophorus rhododactyla*, Denis & Schiffermuller, 1775, *Emmelina monodactyla* Linnaeus, 1758 and *Platyptilia carduidactylus*, Riley, 1869 was recorded for the first time at Paradip, Odisha, India. These three species belong to plume moth categories and are global invasive pests of certain plant types. With identification based on photographs. In this note discuss the synonym, description, material examined, distribution, and remarks. Additionally, *C. rhododactyla*, *E. monodactyla* and *P. carduidactylus* is a new record for the Indian fauna.
Keywords: New records, Invasive species, Pterophoridae, Plume T-moth, Paradip, Odisha.

INTRODUCTION

Insects are very successful and adaptable to diverse settings, making them the most widespread and dominant animal group. Insects are ubiquitous and cover nearly 70% of the Earth's surface. According to Chapman (2009), there are approximately 965,431-1,015,897 described insect species worldwide. The order Lepidoptera is the second largest and most diverse group in the class Insecta. Mallet (2007), states that currently there are around 174,250 Lepidoptera species, with 156,300 nocturnal moths and the remaining being diurnal butterflies. India ranks as one of the world's 17th mega-diversity countries, with the richest and most diversified entomofauna. India is home to approximately 65,000-70,000 insect species, accounting for 7%-10% of the global entomofauna population. India's insect biodiversity is unusual, with about one-third of the known entomofauna being indigenous.

The economically significant species of plume moths, or Pterophoridae, include the artichoke plume moth, which is a nuisance on artichokes, and the grape plume moth, which is a pest on grapes (Silverson & Solis, 2014). The artichoke plume moth *Platyptilia carduidactyla* is a significant pest of the artichoke agroecosystem in California (Ryder et al., 1983). The artichoke plume moth's larvae consume every part of the plant. The Mediterranean region, which includes Europe and northern Africa, has a different artichoke environment than California. In New Zealand, where artichokes are relatively new, general pest issues are not too concerning. Snyder (1981), assembled a list of insects and other invertebrate species related to artichokes based on a recent assessment, taking into account their traits and ability to harm the artichoke crop. Stehr (1987) stated that plume moth larvae can feed on thistle stems, flower heads, or leaves, as well as other hosts from the Asteraceae family. According to Zwolfer (1988), oviposition occurs in mature flower heads, where larvae can feed on ripening achenes and receptacles. Plume moths are iteroparous, with two generations per year, and occur in several locations.

The Colombian plume moth, or *Cnaemidophorus* smithi, is described. The species is the first member of the Neotropical fauna to belong to the genus *Cnaemidophorus*. There is a Holarctic distribution for *Cnaemidophorus rhododactyla* Denis & Schiffermüller, 1775 (Barnes & Lindsey, 1921; Yano, 1963). In several European nations, it is referred to as a pest of *Rosa* (Aizpurua, 1998). The bud does not flower because the larva creates a hollow in it and kills at least 60% of it. There is only one larva per bud. While it feeds, the larva attaches the leaves to the infected bud by spinning a thin thread of silk. There are little excrement particles visible inside the cavity. At the larval feeding site, the fully developed larva pupates beneath a few silk strands. The adult then makes an appearance (Ozbek, 2008). While *C. rhododactyla* larvae were being raised over the summer of 2007, one tachinid species was raised as a larval parasitoid (Ozbek, 2008).

A member of the Pterophoridae (Plume moth) family, *Emmelina monodactyla* (Linnaeus, 1758) feeds mostly on leaves or borer stems and roots on a variety of host plants (Lange, 1950). Although the species is found practically everywhere globally, its origins are likely in Eurasia (Forbes, 1923). Purrington and Stinner (1988), reveal that the main food sources for *E. monodactyla* are the leaves, roots, and borer stems of several host plants,

especially *Ipomoea batatas.* Ghani et al. (1970-1975), specify that *E. monodactyla* virtually exclusively limited its feeding to the genera *Convolvulus* (*Convolvulus* sp.) and *Ipomea* (*I. batatas*), and it may be able to operate as a biological control agent for *Convolvulus* spp. As an adult, *Emmelina monodactyla* overwinters (Meyrick, 1928) and flies all year round. The hue of the species varies greatly, ranging from a light grey-white to a dark ferruginous brown. With a wingspan ranging from 18 to 27 mm, there is also a significant range in size (Gielis, 1990).

With 1318 species spanning 90 genera globally, the family Pterophoridae is represented in the Superfamily Pterophoroidea (Gielis 2003; Van Nieukerken et al., 2011). Some of the research related to the Pterohoridae family previously in India (Sidhu et al., 2010; Pooni et al., 2019; Pathania et al., 2021; Paunikar and Sharma, 2022). Therefore, these three newly recorded species of plume moths (Family: Pterohoridae) were discovered during the current study in Paradip, Odisha, East India. This study is a preliminary report to help future researchers of the Pterohoridae family.

MATERIAL AND METHODS

Description of the study area

Orissa formerly and now modified as Odisha; the official is an Indian state located in Eastern India. The current study site is located at 20° 17' 21.696" N and 86° 42' 19.0872" E in Paradip (Figure 1). The distance via Cuttack through Paradip for 105 km. In the Jagatsinghpur district of Odisha, India, Paradeep, also written Paradip (formerly spelled Paradweep, also spelled Paradwip), is a large industrial seaport city and municipality located 53 km (33 mi) from Jagatsinghpur city. Paradip, which is 0 feet (0 meters) above sea level, has a tropical wet and dry climate, often known as a savanna climate. The district experiences 28.75ºC (83.75ºF) annually, which is 2.78% hotter than the norm for India. Rainfall in Paradip averages 186.28 millimeters (7.33 inches) per year, with 141.26 wet days (38.7% of the total) occurring there.

Data collection

The present study was conducted in February 2024 at Paradip, Odisha. Data collection methods based on Vijayan and Anbalagan (2023). Identification using the available literature and already-published articles.

Cnaemidophorus rhododactyla, Denis & Schiffermuller, 1775 (Plate I, Figure 2)

Synonymy:

Alucita rhododactyla Denis & Schiffermuller, 1775

Platyptilia koreana Matsumura, 1931

Description:

A characteristic broad-winged plume with white markings on the dorsal side of the thoracic region that is brown, typically orange. Scaled, pale brown, mixed grey-white head appressed. Some have upright scales above the eye and at the collar. Palpae is 1.5 times the diameter of the eye, slender, slightly bent upward, and ringed in brown and white. Grey-brown antennae with short cilia are covered in grey-white scales. Middle and rear legs have two, while the forelegs have one scale brush encircling the bases of the spurs; the color is ochreous-white and brown with rings around the spurs; the hind legs have two equal-length pairs of lengthy spurs. Grey-brown abdomen except the first segment, which is ventrally grey-white, and the distal margins of segments two and three, which are grey-white at the dorsum. The dorsal side end of the abdomen is marked with two black spots.

Figure 1. The study map indicated the areas of examination.

Figure 2. Image of rose plume moth (*Cnaemidophorus rhododactyla*)

Figure 3. Image of T-moth or morning glory plume moth (*Emmelina monodactyla*)

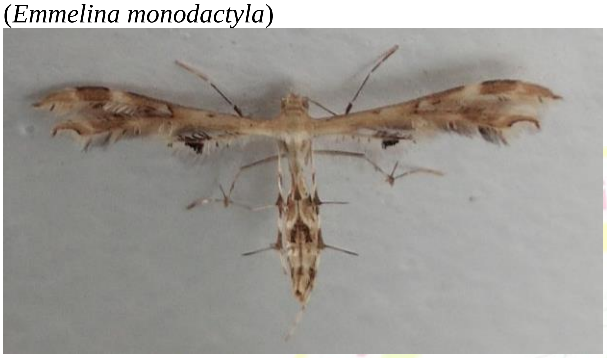

Figure 4. Image of Artichoke plume moth (*Platyptilia carduidactylus*)

Material Examined: One unknown adult, Paradip, Odisha, India, 11. ii.2024 coll. Dr. S. Vijayan

Distribution: East India (Present study), Greenland, North Africa, Northern Hemisphere and Southeast Asia

Remarks: One generation per year, the partially grown larvae overwinter inside the stem of the host plant and begin feeding again in the spring.

Emmelina monodactyla Linnaeus, 1758 (Plate II, Figure 3)

Synonymy:
Phalaena alucita monodactyla Linnaeus, 1758
Phalaena bidactyla Hochenwarth, 1785
Alucita pterodactyla Hubner, 1805
Pterophorus flaveodactylus, Amary, 1840
Pterophorus cineridactylus Fitch, 1855
Pterophorus naevosidactylus Fitch, 1855
Pterophorus impersonalis, Walker, 1864
Pterophorus pergracilidactylus Packard, 1873
Pterophorus barberi Dyar, 1903
Pterophorus pictipennis Grinnell, 1908
Pterophorus monodactylus cf. rufa Dufrane, 1960

Description: Having its wings folded together and positioned at a straight angle to its body, this prevalent plume species rests. The moth frequently rests with its wings tightly wrapped up, making it challenging to discern whether the wings are divided or cleft. Their colour and patterns can vary, and some other plume species may have superficial similarities. Verifying the identity requires measuring the spur length on the hind legs. The pair nearest the body should have the inner spur much longer than the outer spur. Brown streaks run along the midline of the pale buff dorsal longitudinal stripe on the abdomen.

Material Examined: One unknown adult, Paradip, Odisha, India, 10. ii.2024 coll. Dr. S. Vijayan

Distribution: Asia, East India (Present study), Europe, Japan, North Africa and North America

Remarks: A kind where the adult moth hibernates and there are 2 or 3 overlapping generations. Although they eat a wide range of plants, the larvae are especially fond of bindweed species. *Calluna vulgaris* and *Humulus lupulus* are two more common food plants.

Platyptilia carduidactylus, Riley, 1869 (Plate III, Figure 4)

Synonymy:
Pterophorus carduidactylus Riley, 1869
Platyptilia cardui Zeller, 1873
Platyptilia hesperis Grinnell, 1908

Description:

As an adult artichoke plume moth flies, its brown forewing has a darker costal border that extends to form a triangle at the top of the postmedial line; its hindwing is grey with a little black triangle on the anal margin; both sides of the subterminal line have white borders. The inner margin of the forewing is concave and expands drastically near the tip; the subterminal portion is usually colored crimson. The head is pointed; antennae are serrated with dull brown to brown. Abdomen: The dorsal portion is light brown to pale white and two arrow-shaped marks are presented. Tail portion five is segmented; the first three segments are larger than the last two; the first two segments are pale brown to white and the last three are pale white to medium brown.

Material Examined: One unknown adult, Paradip, Odisha, India, 11. ii.2024 coll. Dr. S. Vijayan

Distribution: East India (Present study), New Zealand, North America, North Mexico and the United States

Remarks: Plume moths are iteroparous, with two generations per year, and occur in several locations. Adults are nocturnal and emerge at night. However, they are also frequently observed on the flowers of herbaceous plants during the day.

OBSERVATIONS

The Pterophoroidea superfamily stands apart from other Lepidopteran insect families due to its tiny moths, long, slender legs, long abdomen, and narrowly clefted wings. The wings have a thin shape. In the forewing, there are 01, 02, and occasionally 3 clefts; in the hindwing, there are 02 clefted. The moths that belonged to the same superfamily are referred to as "plume-moths" in common parlance. When the wings are at rest, they are positioned so that the body is rectangular and has a T-shape. Family: Pterophoridae features include a smooth-scaled head, a lack of chaetosemata and ocelli, an unscaled proboscis, vestiges of a maxillary palpi, a slender labial palpus, cleft wings on the forewing, venous scales at the underside along with veins M3 and Cu2, and double cleft hindwings. The wings are smaller and arranged in a T-shape when they are at rest, with the wings being rectangular. Because these moths are so few,

taxonomical research is exceedingly challenging, and the same moth group presents quite significant challenges for field collections, pinning, stretching, labeling, and identification. Keeping all of the above in mind, the current study focuses on the Pterophorid moths in the area under inquiry.

CONCLUSION

The plume moth mostly consumes leaves, but it also buries the roots and stems of a range of host plants. It might pose a risk to an indigenous plant species. Furthermore, research on the seasonal occurrence of plume moths could be significant. Since plume moths only produce a single generation of *Cnaemidophorus rhododactyla* and two to three generations of *Emmelina monodactyla* and *Platyptilia carduidactylus* each year, they are special and limited in number. Therefore, more biological, molecular, and parasitic research is needed in this survey region.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Aizpurua, G.D.C. 1998. Fauna lepidopterologica en estadio de oruga, detectadas sobre los rosales silvestres, *Rosa canina* y *Rosa* spp. Bol. San. Veg. *Plagas*, **24**, 531-540.

Barnes, W. and Lindsey, A.W. 1921. The Pterophoridae of America, north of Mexico. - Contr. nat. Hist. Lepidoptera N. Am. 4, 280483.

Chapman, A.D. 2009. Number of living species in Australia and the world. 2nd edition Australian Biological Resource Study, Canberra, Australia, 1-78.

Forbes, W.T.M. 1923. Lepidoptera of New York and neighbouring States. Experimental Station Memorials. 68, 729 pp. Cornell University of Agriculture.

Ghani, M.A., Baloach, G.M., Khan, A.G., Habib, R. and Zaffar, T. 1970-1975. Laboratory testing and evaluation of insect enemies of *Halogeton* and Russian thistle and research on biological control of weeds common to Pakistan and the United States. Pakistan Station, Commonwealth Institute of Biological Control, Rawalpindi Pakistan. *Final Report*, 59 pp.

Gielis, C. 1990. Microlepidoptera of Europe – Pterophoridae. In Huemer, P., Karsholt, O. & Lyneborg, L. (Eds), Microlepidoptera of Europe. 1, 220 pp.

Gielis, C. 2003. Pterophoridae & Alucitoidea. World Catalogue of Insects, 4, 1-198.

Lange, W.H. 1950. Biology and systematics of plume moths of the genus *Platyptilia* in California. *Hilgardia*, **119**, 561-668.

Mallet, J. 2007. Taxonomy of Lepidoptera: the scale of the problem. The Lepidoptera Taxome Project. University College, London.

Meyrick, E. 1928. A revised handbook of British Lepidoptera. London. 914 pp.

Ozbek, H. 2008 *Cnaemidophorus rhododactyla*, a New *Rosa* spp. Pest for Turkey, and Its New Parasitoids. *Phytoparasitica*, **36**(5), 502-504.

Pathania, P.C., Gielis, C., Das, A. and Chandra, K. 2021. Catalogue of superfamily Pterophoroidae Kuznestovamp; Stekolnikov (Lepidoptera) of India. *Zootaxa*, 4915(2), zootaxa.4915.2.2. doi: 10.11646/zootaxa.4915.2.2.

Paunikar, S. and Sharma, G. 2022. A preliminary study on the moth diversity of Ranjit Sagar conservation reserve of Punjab. *The Pharma Innovation*, **11**(6), 2494-2498.

Pooni, H.S., Pathania, P.C. and Katewa, A. 2019. Plume moths of family Pterophoridae (Microlepidoptera) from Shiwaliks of North-West India. *Rec. zool. Surv. India*, **119**(3), 256-262.

Purrington, F.F. and Stinner, D.H. 1988. The bindweed plume moth, *Emmelia monodactyla* (Lepidoptera: Pterophoridae): First host record for *Phaeogenes vincibilis* (Hymenoptera: Ichneumonidae). *The Great Lakes Entomologist*, **21**(4), 157-158.

Ryder, E.J., Vos, N.E.D. and Bari, M.A. 1983. The globe artichoke (*Cynara scolymus* L.). *Hort Science*, **18**(5), 646-653.

Sidhu, A.K., Chandra, K. and Pathania, P.C. 2010. A Checklist of Microlepidoptera of India. *Rec. zool. Surv. India*, 1-12.

Silverson, N.J. and Solis, M.A. 2014. Reed Watkins: A Passion for Plume Moths. *News of the Lepidopterist's Society*, **56**(3),142-144.

Snyder, M.J. 1981. Insects and other invertebrates associated with artichokes in New Zealand. Studi sul Carciofo. Proc. 3rd Intern. Congr. Artichoke Studies. 969-975.

Stehr, F.W. 1987. Techniques for collecting, rearing, prese~ing, and studying immature insects. In: Stehr, F.W., ed. Immature insects. Dubuque: KendallMunt Publishing Company, 7-18.

Van Nieukerken, E.J., Kaila, L., Kitching, I.J., Kristensen, N.P. et al. 2011. Order Lepidoptera Linnaeus, 1758. In: Zhang, Z.-Q. (Ed.), *Animal Biodiversity: An Outline of Higher-Level Classification and Survey of Taxonomic Richness*, *Zootaxa*, 212-221. https://doi.org/10.11646/zootaxa.3148.1.41.

Vijayan, S. and Anbalagan, S.A. current and annotated inventory of the faunal diversity found on the Anna University campus in Tamil Nadu, India. *International Journal of Agricultural and Applied Science*, **4**(2), 128-134.

Yano, K. 1963. Taxonomic and biological studies of Pterophoridae of Japan. - *Pacif. Insects*, **5**, 65-209.

Zwolfer, H. 1988. Evolutionary and ecological relationships of the insect fauna of thistles. *Annual Review Entomology*, **33**, 103-122.

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Research Article

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Socioeconomic Determinants of Insect Pest Control Methods' Utilization for Storage in North Central Nigeria

[1]Owojaiye, O. B.*, [2]Kolawole, E. A., [3]Ayembo, E. O., [1]Atibioke, O. A., [1]Akinola-Soji, B. and [1]Johnson, O. M.

[1]Research Outreach Department, Nigerian Stored Products Research Institute, Ilorin, Kwara State
[2]Department of Agricultural Economics and Extension, Landmark University, Omu Aran
[3]Department of Agricultural Education, Kogi State College of Education, Ankpa, Kogi State.
**Corresponding author e-mail: sanjoowojaiye@gmail.com*
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ABSTRACT
The impetus for this study is the need to understand factors influencing the use of insect pest control methods in North Central Nigeria. Specifically, the study described the socioeconomic characteristics of respondents, assessed awareness and use of insect pest control methods, examined farmers' considerations and investigated factors influencing insect pest control decisions. Using a structured interview schedule to elicit information, data was collected by means of multi-stage sampling technique to select a total of 384 cowpea farmers for this study. A purposive selection of Kwara and Niger States paved way for the purposive choice of two agricultural zones in Kwara state and one agricultural zone in Niger state. Percentages, frequency counts, ranks, mean, and ordinary least square regression was used to analyze the data. The study revealed that the intended time of sale, time required to apply method, and time of application were the factors most considered for store insect pest control. Ordinary Least Square regression estimates demonstrate positive significant relationship between farm size (t=4.681), group membership (t=4.688), and quantity stored in tons (t=2.312) and intensity of use. Conversely, years of education (t=-2.196), years of cowpea farming experience (t=-3.419), and frequency of extension contact (t=-.534) had significant negative relationship with intensity of use. In conclusion, it is recommended that policy makers and extension staff put into consideration farm size, group membership, quantity stored, years of education, years of cowpea farming experience and frequency of extension contact in optimizing extension strategy for promotion of indigenous and alternative insect pest control methods.
Keywords: alternative, conventional, grains, indigenous, storage.

INTRODUCTION

The importance of insect pest control as a logical attempt to protect crops both in field and in store is well recognized. It is driven by the need to guarantee the availability of food, a key pillar of food security, and the desire to preserve investments. Insect pest control is all the more expedient since about 70% of the farming communities are smallholders (Akpan *et al.*, 2014), who have to contend with other inherent distinctiveness of the agricultural sector in Nigeria such as its rain-fed nature, vulnerability to climate change effects, and its subsistence and traditional characteristics (Kelemu, 2015). Crop production is the dominant subsector of the agricultural sector in Nigeria (Oyaniran, 2020) and the country holds a global competitive advantage in cowpea production. By some distance, Nigeria is the largest producer and consumer of cowpea accounting for 48% of production in Africa and 46% worldwide (IITA, 2017). It supplies food as a cheap source of protein, animal feed and cash for the rural populace (Bashir *et al.*, 2018) in addition to providing ground cover due to the spreading habit of the plant (Claudius-Cole *et al.*, 2014). In spite of the many advantages of the crop, the benefits that would have accrued to farmers and the nation have been severely limited by the activities of insect pests. As a result of the significantly detrimental effects of insect pests, cowpea production activities in Nigeria is trademarked by the use of different insect pest control methods starting from production through storage. Losses of between 20 and 50% have been attributed to insect pests in cowpea (Adebayo and Anjorin, 2018). Insect pest control is therefore imperative for increase in yield, protection of crops, preservation of quality and quantity of crops, safeguarding food availability, and maximization of efficiency. The methods are diverse with farmers embracing perceived proven and effective methods that span indigenous, conventional and alternative.

The conventional method, that is the application of synthetic pesticides, has been more extensively used, however, in recent times and indeed over the past decade, there has been an increased effort to promote indigenous and alternative pest control methods because of the associated human hazards. Underpinning this drive is the quest for responsible production and consumption which is the crux of the 12th Sustainable Development Goal of the United Nations. Accounts of food poisoning leading to death have continued to be reported (Gwary *et al.*, 2012). In the same vein, excessive pesticide use has brought censure on Nigerian agricultural exports. Given the foregoing, this study sought to ascertain the awareness and use of indigenous, and alternative insect pest control methods along with factors influencing their use by cowpea farmers in North Central Nigeria and was guided by an hypothesis stated in the null form as: no significant relationship exists between socio-economic characteristics of respondents and the frequency of use of insect pest control methods in Kwara and Niger States.

MATERIALS AND METHODS

The study was conducted in Kwara (Latitude 8^0 05' and 10^0 05' North and Longitude 2^0 50' and 6^0 05' East of Greenwich Meridian) and Niger (Latitudes $8^0$20' N and $11^0$30' N and Longitudes $3^0$30' E and $7^0$20' E) States. Both states are renowned for high production of cowpea (Bolarinwa *et al.*, 2021). The population comprised all cowpea farmers in both States. A multi-stage sampling procedure was employed to select respondents for the study. The first stage involved the purposive selection of two Agricultural Development Project (ADP) zones (Zone B and C) from the four zones in Kwara State and one zone (Zone I) from the three ADP zones in Niger State. Abdullahi and Tsowa (2014) reported a high concentration of cowpea farmers in Niger State ADP Zone I while Abdullahi (2016) asserted that Kwara State ADP Zone B and C respectively are more involved in cowpea production than other zones in Kwara State. The second stage involved the purposive selection of two local government areas (LGAs) namely Patigi and Edu (Zone B; Kwara State) Asa and Ilorin East (Zone C; Kwara State) and Edati and Mokwa (Zone I; Niger State) to ensure adequate representation of population in drawn sample. The third stage was the proportionate sampling of 112, 117 and 155 cowpea farmers to make for a total of 384 respondents. Data was obtained using a structured interview schedule and was analyzed using both descriptive (percentages, frequencies, means & ranks) and inferential (Ordinary Least Square Regression) statistics.

RESULTS AND DISCUSSION

Socioeconomic characteristics

As shown in Table 1, cowpea cultivation in Kwara and Niger States is male dominated (80.2%) and reflects the male-dominated nature of many societies in North Central Nigeria. The average land area cultivated is 3.6 hectares while the average quantity of cowpea stored was 4.1tons in the last farming season; cowpea farmers in Kwara and Niger States could be considered small scale farmers. The average age of the respondents was 48.9 years and 22.4% had received some form of tertiary education.

Awareness and Use of Insect Pest Control Methods in Store

Awareness is generally a precursor to utilization and adoption. There is a relatively high awareness of indigenous methods among respondents. For alternative pest control methods, PICS Bag (74.7%), Heat/steam treatments (61.5%), Hermetic Steel Drum (59.1%), and Silos (58.1%) were the most known. About half of respondents were aware of Cold Treatment (49.0%), and ZeroFly® hermetic bag (50.3%) in the study area. PICS Bag has been popularized through the Agricultural Development Projects (ADPs) in Nigeria for more than a decade. Alalade *et al.*, (2017) that majority of farmers in Kwara State were aware of the indigenous pest control methods. There is greater awareness (93.8%) and use (87.8%) of use of conventional methods to control cowpea insect pest than other methods. Sabo *et al.* (2014) affirmed that up to 99% of farmers use synthetic pesticides to control cowpea pest attack. The use of plant extracts in Kwara and Niger States is low despite a high percentage of farmers being aware.

Table 1. Socioeconomic Characteristics

Variables	Frequency (n=384)	Percentage	Mean (Std Dev.)
Sex			
Male	308	80.2	
Female	76	19.8	
Age (years)			48.9 (10.71)
21 – 40	89	23.2	
41 – 60	247	64.3	
61 and above	48	12.5	
Cowpea Farm size (Hectares)			3.6 (2.59)
Less than 1.0	10	2.6	
1.0 – 5.0	314	81.8	
6.0 – 10.0	45	11.7	
10.1 and above	15	3.9	
Level of Education			
0 year (No formal education)	121	31.5	
1-6years (Primary education)	104	27.1	
7-12years (Secondary education)	73	19.0	
Above 12years (Tertiary education)	86	22.4	
Quantity Stored (Tons)			4.1 (11.66)
Less than 1	141	36.7	
1 – 10	209	54.4	
11 – 20	25	6.5	
Above 20	9	2.3	

Source: Field Survey, 2021

Table 2. Awareness and Use of Insect Pest Control Methods in Store

Pest Control Methods	Aware	Not Aware	Used	Not Used
Indigenous				
Admixture with wood ash	310(80.7)	74(19.3)	218(56.8)	166(43.2)
Application of Neem extracts	311(81.0)	73(19.0)	195(50.8)	189(49.2)
Use of Jerry Cans	342(89.1)	42(10.9)	308(80.2)	76(19.8)
Storing unthreshed	337(87.8)	47(12.2)	269(70.1)	115(29.9)
Sunning at regular intervals	352(91.7)	32(8.3)	297(77.3)	87(22.7)
Admixture with fine sand	219(57.0)	165(43.0)	112(29.2)	272(70.8)
Admixture with clay dust	159(41.4)	225(58.6)	101(26.3)	283(73.7)
Oils (sunflower, cotton seed, groundnut)	225(58.6)	159(41.4)	166(43.2)	218(56.8)
Conventional				
Synthetic pesticides	360(93.8)	24(6.3)	337(87.8)	47(12.2)
Alternative				
ZeroFly® bag	193(50.3)	191(49.7)	109(28.4)	275(71.6)
Cold Treatment	188(49.0)	196(51.0)	145(37.8)	239(62.2)
PICS Bag	287(74.7)	97(25.3)	251(65.4)	133(34.6)
Heat/steam treatments	236(61.5)	148(38.5)	177(46.1)	207(53.9)
Hermetic Steel Drums	227(59.1)	157(40.9)	169(44.0)	215(56.0)
Silos	223(58.1)	161(41.9)	160(41.7)	224(58.3)

Source: Field Survey, 2021

Table 3. Frequency of Use of Insect Pest Control Methods in Store

Pest Control Methods	Always used	Sometimes used	Never Used	Mean (SD)
Indigenous				
Admixture with wood ash	90(23.4)	128(33.3)	166(43.2)	0.80(0.79)
Application of Neem extracts	109(28.4)	86(22.4)	189(49.2)	0.79(0.86)
Use of Jerry Cans	169(44.0)	139(36.2)	76(19.8)	1.24(0.76)
Storing unthreshed	135(35.2)	134(34.9)	115(29.9)	1.05(0.81)
Sunning at regular intervals	160(41.7)	137(35.7)	87(22.7)	1.19(0.78)
Admixture with fine sand	35(9.1)	77(20.1)	272(70.8)	0.38(0.65)
Admixture with clay dust	51(13.3)	50(13.0)	283(73.7)	0.40(0.71)
Oils (sunflower, cotton seed, groundnut)	87(22.7)	79(20.6)	218(56.8)	0.66(0.83)
Conventional				
Use of synthetic pesticides	223(58.1)	81(21.1)	80(20.8)	1.37(0.81)
Alternative				
ZeroFly® bag	34(8.9)	75(19.5)	275(71.6)	0.37(0.64)
Cold Treatment	64(16.7)	81(21.1)	239(62.2)	0.54(0.73)
PICS Bag	102(26.6)	149(38.8)	133(34.6)	0.92(0.78)
Heat/steam treatments	67(17.4)	140(36.5)	177(46.1)	0.71(0.74)
Hermetic Steel Drum	61(15.9)	108(28.1)	215(56.0)	0.60(0.75)
Silos	83(21.6)	77(20.1)	224(58.3)	0.63(0.82)

Source: Field Survey, 2021

Table 3. Frequency of Use of Insect Pest Control Methods in Store

Pest Control Methods	Always used	Sometimes used	Never Used	Mean (SD)
Indigenous				
Admixture with wood ash	90(23.4)	128(33.3)	166(43.2)	0.80(0.79)
Application of Neem extracts	109(28.4)	86(22.4)	189(49.2)	0.79(0.86)
Use of Jerry Cans	169(44.0)	139(36.2)	76(19.8)	1.24(0.76)
Storing unthreshed	135(35.2)	134(34.9)	115(29.9)	1.05(0.81)
Sunning at regular intervals	160(41.7)	137(35.7)	87(22.7)	1.19(0.78)
Admixture with fine sand	35(9.1)	77(20.1)	272(70.8)	0.38(0.65)
Admixture with clay dust	51(13.3)	50(13.0)	283(73.7)	0.40(0.71)
Oils (sunflower, cotton seed, groundnut)	87(22.7)	79(20.6)	218(56.8)	0.66(0.83)
Conventional				

Use of synthetic pesticides	223(58.1)	81(21.1)	80(20.8)	1.37(0.81)
Alternative				
ZeroFly® bag	34(8.9)	75(19.5)	275(71.6)	0.37(0.64)
Cold Treatment	64(16.7)	81(21.1)	239(62.2)	0.54(0.73)
PICS Bag	102(26.6)	149(38.8)	133(34.6)	0.92(0.78)
Heat/steam treatments	67(17.4)	140(36.5)	177(46.1)	0.71(0.74)
Hermetic Steel Drum	61(15.9)	108(28.1)	215(56.0)	0.60(0.75)
Silos	83(21.6)	77(20.1)	224(58.3)	0.63(0.82)

Source: Field Survey, 2021

Table 4. Factors Considered for Insect Pest Control in Store

Factors	No Not Important	Yes Important	Very important	Mean (SD)	Rank
Intended time of sale	29(7.6)	121(31.5)	234(60.9)	1.55(0.633)	1st
Time required to apply control method	40(10.4)	123(32.0)	221(57.6)	1.47(0.677)	2nd
Time of application	37(9.6)	143(37.2)	204(53.1)	1.43(0.663)	3rd
Quantity of required	43(11.2)	137(35.7)	204(53.1)	1.42(0.685)	4th
Cost of control method	44(11.5)	145(37.8)	195(50.8)	1.39(0.685)	5th
Climatic and environmental condition	21(5.5)	191(49.7)	172(44.8)	1.39(0.591)	6th
Type of pest	42(10.9)	153(39.8)	189(49.2)	1.38(0.675)	7th
Availability of pest control method	22(5.7)	196(51.0)	166(43.2)	1.38(0.591)	8th
Quantity of grains to be stored	19(4.9)	206(53.6)	159(41.4)	1.36(0.576)	9th
Familiarity with control method	25(6.5)	200(52.1)	159(41.4)	1.35(0.599)	10th
Labour requirement	41(10.7)	174(45.3)	169(44.0)	1.33(0.661)	11th
Effectiveness of control method	11(2.9)	241(62.8)	132(34.4)	1.32(0.523)	12th
Period of storage desired	51(13.3)	163(42.4)	170(44.3)	1.31(0.693)	13th
Price/cost benefit analysis	28(7.3)	210(54.7)	146(38.0)	1.31(0.600)	14th
Method of application of pest control	33(8.6)	207(53.9)	144(37.5)	1.29(0.615)	15th
Recommendation by extension agents	48(12.5)	200(52.1)	136(35.4)	1.23(0.654)	16th
Advice from agrochemical dealers	65(16.9)	169(44.0)	150(39.1)	1.22(0.716)	17th
Ease of application of method	49(12.8)	214(55.7)	121(31.5)	1.19(0.639)	18th
Period of efficiency of method	79(20.6)	156(40.6)	149(38.8)	1.18(0.750)	19th
Level of infestation	49(12.8)	245(63.8)	90(23.4)	1.11(0.593)	20th
Counsel by researchers	94(24.5)	169(44.0)	121(31.5)	1.07(0.746)	21st
Use by peers	83(21.6)	198(51.6)	103(26.8)	1.05(0.695)	22nd
Tradition	127(33.1)	130(33.9)	127(33.1)	1.00(0.814)	23rd

Source: Field Survey, 2021

Factors Considered for Insect Pest Control Methods in Store

The results of the important factors considered for pest control methods of cowpea in the store is presented in Table 4. The table show that intended time of sale (mean=1.55), time required to apply control method (mean=1.47), and time of application (mean=1.43) were ranked first, second and third factors indicated by respondent and implies that intended time of sale, time required to apply control method, and time of application were the leading factors considered for cowpea store pest control methods in Kwara and Niger States. The prominent concerns of cowpea farmers in this study are met by synthetic pesticides and explains its high use.

Determinants of Use of Insect Pest Control Methods

As shown in Table 5, the socioeconomic determinants are made up of six variables which significantly determine the frequency (intensity) of use of pest control methods in the study area hence the research hypothesis was rejected. The coefficient of farm size in hectares (t=4.681), group membership (t=4.688) and quantity stored in tons (t=2.312) are positive and indicate that a unit increase in the hectare of land cultivated, year of membership in group, and tons of cowpea stored by the farmers will increase their frequency of use of insect pest control methods. Large farm sizes connote increased investment, and may lead to a greater reliance on a control method to protect grains and investments. In like manner, large cowpea quantities in store would heighten the need for protection. On the other hand, the negative coefficient of years of education (t=-2.196), years of cowpea farming experience (t=-3.419), and frequency of contact with extension (t=-.534) imply probability for reduced frequency of use of pest control methods at every unit increase in years of education, frequency of extension contact and years of cowpea farming experience. Education improves knowledge as does the frequency of contact with extension since both exposes the farmer to a gamut of options and widens the farmer's know-how.

Table 5. Ordinary Least Square Estimates of the Determinants of Frequency of Use

	Coef. (β)	Std. Error	t-value	*P*>|*t*|
(Constant)	30.593	4.190	7.301	0.000
1. Sex	-.186	1.141	-.163	0.871
2. Age	-.037	.056	-.656	0.512
3. Marital Status	-.738	.672	-1.098	0.273
4. Education	-.914	.416	-2.196	0.029*
5. Farm Size	1.073	.229	4.681	0.000*
6. Household Size	-.195	.222	-.877	0.381
7. Primary Occupation	-.812	.456	-1.782	0.076
8. Group Membership	4.880	1.041	4.688	0.000*
9. Group Type	.386	.264	1.463	0.144
10. Income	4.249	.000	.430	0.667
11. Quantity Stored	.104	.045	2.312	0.021*
12. Farming Experience	-.187	.055	-3.419	0.001*
13. Land ownership	-.092	.245	-.375	0.708
14. Extension contact	3.797	2.528	1.502	0.134
15. Frequency of extension contact	-.534	.574	-.931	0.000*
16. Types of Cowpea grown	-.254	.143	-1.785	0.075
17. Cropping system	.149	.928	.160	0.873
18. Source of Pesticide	-1.573	.390	-4.037	0.976

Source: Field Survey, 2021

CONCLUSION

The factors that significantly affect the utilization of insect pest control methods among respondents are restricted to farm size, group membership, quantity stored in tons years of education, years of cowpea farming experience and frequency of extension contact. These form the array of important predicators and it is recommended that these factors are considered in the deployment of extension strategy for achieving greater utilization of safe and eco-friendly indigenous and alternative insect pest control methods among cowpea farmers in Kwara and Niger States.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Abdullahi, A. and Tsowa, M. 2014. Economics of cowpea production under small-scale cowpea Enterprise in Agricultural Zone I of Niger State, Nigeria. *IOSR Journal of Agriculture and Veterinary Science* (IOSR-JAVS). **7**(4): Ver. III, PP 84-94.

Abdullahi, M. J. 2016. Analysis of Farmers' Efficiency in Cowpea Production in Kwara State, Nigeria. *Unpublished M.Sc. thesis*. Ahmadu Bello University.

Adebayo, R. A. and Anjorin, O. O. 2018. Assessment of Entomocidal Effects of Solar Radiation for the Management of Cowpea Seed Beetle, *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae) in Stored Cowpea. *Global Journal of Science Frontier Research: Agriculture and Veterinary Science* **18**(2).

Akpan, S. B. Udoh E. J. and Udo U. J. 2014. Monthly Price Analysis of Cowpea (beans) and Maize in AkwaIbom state, Southern Nigeria. *International Journal of Food and Agriculture* **2**(2): 65-86 .

Bashir, M.B., Ndaghu, A. A., Nakwe, S.H.G., Abdulazeez, A.W., Samuel, R.T. 2018. Adoption of Cowpea Production Technologies among Farmers in Taraba State, Nigeria. *Journal of Agriculture and Veterinary Science* **11**(3) 37-46.

Bolarinwa, K. A., Ogunkanmi, L. A. and Ogundipe, O. T. 2021. An investigation of cowpea production constraints and preferences among small holder farmers in Nigeria. *Geo Journal*. https://doi.org/10.1007/s10708-021-10405-6.

Claudius-Cole, A. O., Ekpo, E. J. A. and Schilder, A. M. C. S 2014. Evaluation of Detection Methods for Cowpea Bacterial Blight Caused by *Xanthomonas Axonopodis* Pv *Vignicola* inNigeria. *Tropical Agricultural Research & Extension* **17**(2): 2014. 77-85.

Gwary, O. M., Hati, S. S., Dimari, G. A. and Ogugbuaja, V. O. 2012. Pesticide Residues in Bean Samples from North eastern Nigeria, *ARPN Journal of Science and Technology*, **2**(2), 79-84

IITA 2017. Cowpea. Retrieved from https://www.iita.org/cropsnew/cowpea/ on 27th July, 2022.

Kelemu, F. 2015. Agricultural mechanization in Ethiopian: Experience, status and prospects. *Ethiopian Journal of Agricultural Sciences*, **25**(1), 45–60.

Oyaniran, T. 2020. Current State of Nigeria Agriculture and Agribusiness Sector. Pricewatercoopers 2020. Accessed 24h July, 2022.

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Review Article

Soil Acidity Causes in Ethiopia, Consequences and Mitigation Strategies-A Review

Amanuel Tadesse
Oromia Agricultural Research Institute, Nekemte Soil Research Center, Oromia, Ethiopia
**Corresponding author e-mail: amanueltadesse2021@gmail.com*
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ABSTRACT
Soil acidity is a serious land degradation problem and worldwide danger, impacting approximately 50% of the world's arable soils and limiting agricultural yield. Soil acidification is a complicated series of events that lead to the production of acidic soil. In its widest sense, it can be defined as the total of natural and human processes that reduce the pH of soil solutions. Soil acidity affects around 43% of agricultural land in Ethiopia's humid and sub humid highlands. Acid soils in western Ethiopia are mostly caused by topsoil erosion caused by heavy rains and high temperatures. This results in the loss of organic matter and the leaching of exchangeable basic cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}). Because ammonium-based fertilizers are easily converted to nitrate and hydrogen ions in the soil, they play a significant role in acidification. One of the reasons of soil acidity is inefficient nitrogen usage, which is followed by alkalinity exports in crops. Soil acidity in Ethiopian highlands is mostly caused by the clearance of crop residues, continuous crop harvest without sufficient fertilization, cation removal, and usage of acid-forming inorganic fertilizers. Acid soil reduces nutrient availability and produces Al and Mn toxicity. In addition to these effects, soil acidity may rapidly degrade soil physicochemical qualities such as organic carbon (OC), cation exchange capacity (CEC), soil structure, porosity, and texture. Liming, the use of organic materials as ISFM, and the adoption of crop types that are resistant to Al toxicity are all alternatives for correcting acid soils. Liming can minimize toxicity by lowering concentrations, improving the availability of plant nutrients like P, Ca, Mg, and K in the soil, and reducing heavy metal solubility and leaching. Application of organic matter has a liming impact because of its abundance in alkaline cations (such Ca, Mg, and K) that were released from OM during mineralization. The pH of the soil is raised by soil organic matter, which helps with soil acidity supplements.
Keywords: Soil Acidity, Liming, nutrient availability.

INTRODUCTION

The main factor impeding the agricultural systems of many emerging nations is soil deterioration. South Africa's Ethiopia is a developing nation that faces significant challenges related to soil degradation. Acidification and salinization are the two primary processes that cause soil degradation. About 50% of the world's potentially arable soils are affected by soil acidity, which is one of the main issues causing land degradation and a worldwide danger. It is also one of the main factors limiting crop yield. In Ethiopia's humid and sub-humid highlands, it affects around 43% of the agricultural area (Sumner and Noble, 2003; Kochianet et al., 2004; Agegnehuet al., 2019).

Sustainable agricultural productivity has been hindered by the issues in almost all of Ethiopia's producing regions. Ethio SIS (2014) estimates that highly acid soils (pH 4.1–5.5) account for around 28.1% of Ethiopia's soils and that soil acidity affects about 43% of the country's arable land. Due to potential toxicities of aluminum and manganese as well as deficits in calcium, magnesium, phosphorus, and molybdenum (Mo) (Barber, 1984; ATA, 2014; Abebe, 2007; Agegnehuet al., 2019; 2021). Strongly acidic soils are often infertile. Moreover, one of the main factors impeding profitable and sustainable agricultural output in many African nations, as well as in many other parts of the world, is soil acidity. According to Osundwa et al. (2013), it has a detrimental effect on nutritional availability and results in Al and Mn toxicity. Moreover, acidity of the soil can quickly deteriorate the physico-chemical characteristics of the soil, including its structure, porosity, texture, cation exchange capacity (CEC), and soil organic carbon (OC). The complexation of metals with organic matter, the dispersal of colloids, and the ultimate bioavailability of trace elements are all impacted by acidification (Bolan et al., 2003). Reduced land productivity is the result of a fall in pH, which raises net charge (low in CEC) and causes a loss of soil fertility.

This illustrates the extent to which agricultural productivity is being jeopardized by soil acidification, hence diminishing food security, especially in the highlands of Ethiopia, where the environment favors soil

acidification processes (Agegnehuet al., 2019; Hossainet al., 2021). In the Ethiopian highlands, where most people depend on agriculture for a living, it is one of the primary environmental hazards (Fanuel and Kibebew, 2021).

Ethiopia's political, economic, and social growth is still largely dependent on agriculture, which also has the greatest influence in these areas. Furthermore, according to the NBE Annual Report 2017–2018, it is a major contributor to Ethiopia's economy, accounting for over 35% of the nation's GDP, 66% of jobs, and over 76% of total export revenue. Soil is vital to this industry. The agricultural GDP is mostly composed of crops (72%), with livestock (20%) and other sectors (8.6%) making up the remaining 20%. The majority of crops produced as primary staples are cereals, which include wheat, maize, tef, sorghum, and millet (CSA, 2019/20).

Furthermore, a vast range of crops are cultivated, including fruits, vegetables, oilseeds, legumes, and spices. Because of enhanced soil management, higher yields, and horizontal expansion, cereal output has grown by 6.21% over the prior season and more than quadrupled over the previous ten years (CSA, 2019–20). However, food security continues to be a major concern for a lot of households and the nation at large. For instance, the World Food Program (2017) reported that 5.6 million Ethiopians were classified as having a crisis requiring severe humanitarian assistance.

The poor level of agricultural productivity and production, which is impacted by low soil fertility and soil degradation, is one of the primary factors limiting food poverty. According to Kassaye Gurebiyaw and Abay Gelanew (2019), human activity is the primary cause of Ethiopia's declining soil fertility since it cultivates unkempt regions without using soil conservation techniques and has inadequate soil cover.

Chemical processes such as soil acidity and alkalinity affect plant nutrition availability. It is believed that the two main crop production restrictions that pose the greatest danger to the global food production system and, consequently, food security are soil acidity and soil calcareousness (Hossain et al., 2021). Despite the fact that Ethiopia is home to a sizable section of East Africa's greatest croplands, the country's natural features and the heavy fertilizer use on many of its farms have caused widespread soil acidity and desertion. According to Kassaye Gurebiyaw and Abay Gelanew (2019), human activity degrades Ethiopian soil when impoverished regions are cultivated without employing soil conservation measures and have insufficient soil cover.

This makes the environment difficult for the nation to improve staple crop yields and food supplies, especially when combined with the loss of topsoil (Gurmessa, 2020). Acidity in soils results from the replacement of basic elements by hydrogen ions in soil colloids, which include calcium, magnesium, sodium, and potassium. Natural processes like rainfall-induced leaching or human-caused activities like heavy fertilizer application and ongoing cultivation without organic inputs may both remove bases from an environment.

N-based fertilizers have varying effects depending on the situation, although they may cause acidity to rise if some N is lost through leaching (Tully et al., 2015; McCauley, 2017). In Ethiopia, urea (46N-0-0) and diammonium phosphate (DAP) (18N-46P2O5-0) applied repeatedly over many years were reported to be favoring factors for soil acidification in the country's Northwestern and Southwestern highlands, despite the fact that inorganic fertilizers were applied in small amounts (Laekemariam et al., 2016; Eyasu et al., 2019).

Ethiopia's total clearance of crop leftovers from crop fields, excessive grazing, and heavy rainfall all contribute to the country's increased soil acidity problems by robbing organic matter and basic cations through soil erosion and leaching (Abebe, 2007; Abate et al., 2017; Elias, 2021). Numerous research have indicated that heavy rainfall regions in Ethiopia's southwest, northwestern, southern, and western regions are particularly plagued by the issue of acidity in the soil (Kebede and Yamoah, 2009; Warner et al., 2016). On the other hand, the soils in the country's north and east are alkaline (ATA, 2014; Agegnehue et al., 2019).

This problem of soil acidity poses a serious threat to the nation's future agricultural output because it raises the concentration of aluminum (Al3+) in the soil solution to a toxicity level (Alvarez et al., 2020), restricts crop performance (Fageria and Baligar, 2008), and limits the availability of vital plant nutrients (Wendimu, 2021). This would suggest that one of the main obstacles to achieving sustainable production and food security is soil acidity and the resulting limited nutrient availability. Soil fertility and health have continued to be key components in raising and maintaining crop yields in order to meet the world's growing need for food and raw commodities.

This means that in order to optimize agricultural output, knowledge of soil acidity and how to mitigate it must be applied appropriately. Therefore, obtaining sustainable levels of agricultural output requires a thorough investigation of appropriate management strategies. The country's highlands have seen the creation of several strategic strategies for the control of soil acid.

Numerous research projects have focused on soil management, which affects agricultural yield and the physiochemical properties of the soil in different ways. So, the main objective of this seminar is to highlight different literatures on the concepts of soil acidity and to give a wealth of knowledge on the sources of soil acidity, the effects it has on agricultural production, and management strategies for reducing soil acidity and raising crop yield. This is predicated on an extensive literature study and synthesis conducted within the Ethiopian setting.

Soil Acidity, Extent and its Distribution in Ethiopia

Global food production is severely hampered by acidic soil, which is defined as pH less than 5.5 (FAO and ITPS, 2015). It happens when high numbers of hydrogen (H^+) ions combine with clay particles, releasing aluminum that then generates more H+ ions. Natural processes

include the interaction of CO2 with water, the uptake of excess cation by plant roots over anion nutrients, and the breakdown of organic matter—which is particularly severe in podzols and histosols—all contribute to the formation of H^+ ions. The clay minerals easily adsorbe aluminum and hydrogen, releasing Ca^{2+}, Mg^{2+}, and K^+ ions that can then be leached from the soil by percolating water, resulting in shortages in these elements (Blum, Shad, and Nortcliff, 2018).

Thus, in many developing nations where food production is vital, acid soils restrict agricultural yields. Because of nutritional inadequacies, diseases, and the toxicity of aluminum, manganese, and hydrogen activity, as well as the unavailability of vital elements including calcium, magnesium, molybdenum, and phosphorus, acid soils are phytotoxic (Hede et al., 2001; Taye, 2007). Plant development in acidic soils is strongly impacted by aluminum's dominance on the ion exchange complex, especially in agronomic crops. One specific management issue is aluminum toxicity, which mostly happens when water has a pH of less than 5.0. Abdenna et al. (2007) ascribe the rising trend of exchangeable Al^{3+} and soil acidity in arable and abandoned areas to intensive farming practices and ongoing use of inorganic fertilizers that generate acids. The loss of nutrients through leaching, the loss or decrease in the availability of specific plant nutrients (like P, Ca, Mg, and Mo), the increase in the solubility of toxic metals like Al and Mn, which may affect root growth and nutrient and water uptake, and alterations to microbial populations and activities are other changes in soils that may happen during soil acidification (Marschner, 2012; Abdenna et al., 2013). Although the degree of change may depend on a variety of features within a particular soil, such changes will frequently be followed by changes in the pH of the soil overall.

In the western region of Ethiopia in particular, and in much of the country's highlands overall, soil acidity has emerged as a major danger to agricultural production (Taye, 2007). Previous research by Mesfin (2007) found that soil acidity, or Al3+ toxicity, affects around 41% of Ethiopia's agricultural areas. The state of the acidity of the Nitisols found in western and central Ethiopia was assessed in 2006 by an inventory. The findings showed that all samples were acidic, but to varying degrees depending on the region (Abdenna et al., 2007). Ethiopian soil acidity is increasing in both extent and amplitude, which is substantially reducing crop productivity (Wassie and Shiferaw, 2011; Tamene et al., 2017). According to a recent study by Eyasu (2016), 80 percent of the Nitisols and Luvisol subgroup soils in Ethiopia's north-central and south-western highlands have a pH of 4.5 to 5.5, making them extremely strong to strongly acidic soils. As a result, one of the obstacles to maintaining agricultural productivity and output in western Ethiopia was the acidity and low fertility of the land. According to Eyasu and Elias (2016), mismanagement and ongoing degradation processes that have taken a toll on the soils for generations are to blame for the rising depletion and turning of Ethiopia's north-central and south-western highlands' soils into infertile ones. Additionally, he enumerated low amounts of organic matter, acidic soil responses, and deficits of key critical plant nutrients as the main fertility obstacles and concerns in this region. The primary soil classifications characterized by acidity are nitisols; over 80% of landmasses derived from nitisols may be acidic, in part due to basic cation leaching (IFPRI, 2010; Eyasu, 2016). Both the most fertile and most acidic regions of Ethiopia are found in the southwest of the nation. Gimbi, Nedjo, Hosanna, Sodo, Chencha, Hagere-Mariam, Endibir, and the Awi Zone of the Amara regional state are among the regions that are known to be negatively impacted by soil acidity (Tamene et al., 2017).

In spite of these broad numbers, there remains a lack of localized understanding and current severity assessments for the issue. Soil acidity in high rainfall areas (roughly 41 percent of cultivated land; Mesfin, 2007) is becoming a major production constraint, even though the extent, distribution, causes, and management of problematic soils in Ethiopia are not well documented. (Getachew and Tilahun, 2017).

Abdenna (2013) reported that soils from several areas in the West Wollega, East Wollega, and West Showa zones had pH values that were outside of the typical range needed for agricultural cultivation. The availability of vital nutrients is severely impacted by such a low pH. Aluminum's toxicity to plants has a significant impact on nutrient and water absorption, as well as root and shoot development. Additionally, there is an impact on the actions of microbes, which are essential to the cycling of nutrients in agroecosystems. In south-western Ethiopia, the soils in the districts of West Wollega, East Wollega, and West Showa are acidic to varying degrees. A small number of the soils are moderately to slightly acidic, while the majority are extremely highly acidic (Abdenna, 2013).

Tropical and subtropical areas have a serious issue with soil acidity (Bordeleau and Prevost, 1994). Strong soil acidity, which impacts 28% of Ethiopia's total land area and 43% of its agricultural land—mostly in the highlands of Oromiya, Amhara, and the Southern Nation Nationalities and Peoples region—poses a major danger to crop output in the country (Tegbaru) (2015). The capacity of the soil to carry out its tasks in a sustainable way is known as soil quality (Lal, 2015). The biophysical and chemical characteristics of soil undergo gradual changes over time, which are expedited by management strategies.

Crop productivity on acidic soils, primarily the Nitisols of the Ethiopian highlands, is severely limited by the acidity of the soil and the resulting reduced nutrient availability (Zeleke et al., 2010). According to Haile et al. (2017), soil acidity affects around 43% of Ethiopia's farmed land. According to an evaluation of Ethiopia's soil acidity, highly acid soils (pH 4.1–5.5) account for around 28.1% of all soils (ATA, 2014). The western Ethiopian highlands have places with high acidity,

especially in the highland sections of SNNP (Amede et al., 2001) and the western and central highlands of Oromia and Amhara (Deressa et al., 2007; Tilahun et al., 2019).

According to Dessa et al. (2007), 43% of Ethiopia's arable land is thought to be acidic overall. According to more recent evaluations, Ethiopia's soil acidity is becoming more widespread and severe, which has a negative impact on agricultural productivity (Lulu et al., 2020). For instance, farmers have switched to planting oats that are more tolerant of acidic soil in several barley, wheat, and fababean-growing regions of the central and southern Ethiopian highlands (Haile, 2009; Agegnehu et al., 2019). To lessen the detrimental impacts of soil acidity and increase soil fertility, many farmers use a barley-fallow-oats rotation system (Regassa and Agegnehu, 2011). But according to Alemu et al. (2017), this rotation method is not sustainable, and using lime to neutralize soil acidity appears to be essential for long-term sustainability.

Ethiopian soil acidity frequently occurs in areas where high levels of precipitation and unfavorable temperatures combine to leach sizable amounts of exchangeable basic ions from soil surfaces, such as calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) (Mesfin 2007). The impact of parent materials, landform, vegetation, and climatic pattern all contribute to its very varying intensity (Achalu et al., 2012).

Major Acid Soils

Eutric In the central highlands of Ethiopia, where soil acidity is an issue, nitisol is the predominant soil type. The predominant soil type that covers Ethiopia's western region is nitisol (Abebe, 2007). These soils, which range in color from reddish brown to red clay, were created by intense weathering in humid environments. Their fertility is dependent on the base saturation, which is considered to be medium to high, and they have a significant inclination toward erosion despite having good drainage. Since nitisols have a solid structure and a large capacity for storing water, they offer excellent agricultural potential.

Even in the dry season or soon after precipitation, workability on these soils poses no issues. Land preparation is not difficult. According to Abebe (2007), these soils often contain very little accessible P and a rather low CEC for their clay concentration. Acidic parent material, which is found in heavy rainfall locations linked to nitisols and cambisols, is often the source of acrisols. Moderate to steep slopes are home to these soil types. They are only marginally suitable for agriculture; some of them are farmed, while some are left uncultivated for grazing. In general, the pH value is below neutrality and base saturation is low.

Abebe (1998) states that acrisols are the end product of intense weathering and leaching-induced base depletion. The steady loss of soil bases (such as Ca, Mg, and K) has resulted in the development of soil acidity under acidic soil conditions. The high amounts of aluminum (Al) and manganese (Mn) combined with the shortage of P, nitrogen (N), sulfur (S), and other nutrients cause soil acidity, which is most felt at soil pH <5.5, to hinder crop development (Abreha, 2013). The sub-soil units of nitisols are called eutric, dystric, and humic nitisols respective.

High base saturation in the soil profile, particularly in the A and B layers, and a comparatively high organic matter content in the top layer of dystric nitisol soil reflect the soil's high fertility status. Similar to Dystric Nitisol in terms of reproductive status, Eutric Nitisol has a crimson to dusky red lower lying horizon. On undulating plains, low plateaus, mild hills, and mountains on all areas' side slopes, nitisols are found where the slope ranges from 2 to 16 percent. These soil types have a tight relationship with the acidity issue because of their geographic location, intensive farming, and improper farm management techniques (Abebe, 2007). Generally speaking, acrisols form from acidic parent material that is found in heavy rainfall regions that are also home to nitesols and cambrisols.

Causes of Soil Acidity

Acidic soil is created by a complicated series of processes known as soil acidification. It may be broadly understood as the culmination of both man-made and natural processes that reduce the pH of soil solutions (Brady and Weil, 2016). The problem is made worse by anthropogenic causes such improper land use systems, monocropping, nutrient mining, and insufficient nutrient supplies (Wassie and Shiferaw, 2009; Tamene et al., 2017). The most frequent causes of soil acidity, low soil quality, and low soil fertility in Western Oromia, according to Achalu et al. (2012), were practices of extraordinary deforestation, overgrazing, and intense farming of soils with minimal inputs over many years. According to the same authors, the issue of soil acidity in Oromia, especially in the eastern and western regions, was extremely serious and required quick action to modify the soils in order to produce crops.

Additionally, because of soil acidity, which requires different amendments to improve soil fertility and acidity problems, smallholder farmers in various districts in the East and West Wollega zones have reported crop yield stagnation or even decline. They have also reported a lack of response to the application of urea and diammonium phosphate fertilizers (Abdenna, 2013). Soil physical qualities including bulk density and soil structure have been negatively impacted by the nation's ongoing use of chemical fertilizers that exclusively include N and/or P nutrients in the form of DAP and urea (Brady and Weil, 2008).

Additionally, according to Faragia et al. (2014), the technique may exacerbate soil acidification and reduce the amount of macro- and micro-plant nutrients in the soil to levels below those that are required for the best possible crop development and yield. Because ammonium-based fertilizers are easily converted to nitrate and hydrogen ions in the soil, they have a significant role in the acidity of the soil. One of the main

contributors to soil acidification is the inefficient use of nitrogen, which is followed by product that exports alkalinity (Guo et al., 2010).

Agricultural products (crop wastes) removal

In most of Ethiopia's highland regions, ongoing crop harvesting (without enough fertilization), cation removal, and continuous use of acid-forming inorganic fertilizers all play a significant role in the development of soil acidity. Therefore, issues with soil fertility caused by acidity are significant production barriers in Ethiopia, lowering the yield of the main crops farmed there (IFPRI, 2010). It is known that there are a number of reasons why soils might become acidic. The main sources of acidity in soil are as follows:

Climate

Because there is less water filtration through the soil in arid places, a substantial supply of bases is often available. As precipitation increases, soluble salt concentrations decrease to a minimum and any gypsum and calcium carbonate that may have been present are eliminated. There comes a point at which the rate of base removal outpaces the rate of base release from non-exchangeable forms with additional increases in rainfall. Soils that are more acidic are more likely to occur in wet climates (Tadesse, 2001). The basic components of the soil (Ca, Mg, Na, and K) that keep the soil from becoming acidic are gradually eroded by prolonged heavy rains. Elevated precipitation depletes soluble elements like calcium and magnesium, which are precisely substituted by aluminum from the exchange sites (Brady and Weil, 2016).

Parent Material Acidic Parent Material Furnishing Aluminum and Silicon Ions

Acid rocks, such as granite and rhyolite, are defined as rocks having a higher concentration of quartz or silica relative to their basic material or element content. Even though there is no loss of base throughout the soil formation process, rocks that are lacking in bases become acidic as they crumble or break down during the process of accumulating soil particles. Compared to soils formed from shale or limestone, those formed from worn granite are probably more acidic. Large tracts of sandy, siliceous soil that were formed from acid-parent rocks have always needed lime. But the majority of acid soils are the consequence of agricultural base removal and leaching losses (Brady and Weil, 2016).

Depending on the origin and makeup of the parent materials, Ethiopian soils with varying degrees of intrinsic fertility have formed under a variety of parent materials and climates. For example, the intrinsic soil fertility grown over simple parent materials is quite high, while soils produced from sandstones are poor sandy soils. When alluvium comes from relatively youthful materials in alluvium plains, it becomes rich and productive; when it comes from heavily worn surfaces, it becomes less fertile. The bulk of soils have pH values between 4.5 and 6.5. According to Regassa and Agegnehu (2011), the majority of the time, the soils found in the nation's high-altitude regions have low base saturation, few exchangeable cations, and an acidic response.

Application of Ammonium Fertilizers

Acidity of the soil ultimately rises with continuous use of inorganic fertilizer without soil testing and amendments.

In the end, adding more inorganic fertilizer without doing soil tests or amendments makes the soil more acidic. Acidification is a result of the use of ammonia-based N fertilizers (Fageria and Nascente, 2014; Guo et al., 2010). Acidity is created in the soil when ammonium fertilizers are applied, although the form of N that crops extract is identical to that of fertilizer. Fertilizers based on ammonia (NH4), urea (CO (NH2)2), and proteins (amino acids) in organic fertilizers may all contribute hydrogen. Soil acidity is produced when such sources of N fertilizers are converted into nitrate (NO3), which releases hydrogen ions (H+). The truth is that N fertilizer raises soil acidity by raising crop yields, which raises the quantity of essential components that are extracted during crop harvest without being incorporated. As a result, adding a lot of organic matter to a soil or applying fertilizers containing NH4 might eventually make the soil more acidic and reduce its pH (Guo et al., 2010).

Decomposition of Organic Matter

Acidity results from the production of H^+ ions during the breakdown of organic materials. The short-term impact of soil acidity resulting from organic matter breakdown is negligible. The causes of soil acidity include large amounts of carbonic acid created by higher plants and microbes, as well as by other physicochemical and biological processes. However, the influence of this acid's dissociation is minimal because the majority of it is lost to the atmosphere as CO_2 (Kochian et al., 2004; Paul, 2014).

Reactive carboxylic, enolic, and phenolic groups found in soil organic matter, or humus, operate as weak acids. They release H^+ ions when they separate. Additionally, during the breakdown process, bases on exchange complex are replaced with H^+ ions due to the creation of CO_2 and organic acids (Somani et al., 1996).

Removal of Mineral Elements through the Harvest of High-Yielding Crops

Soil acidity is caused by elemental removal, particularly from soils with tiny reservoirs of bases as a result of high-yielding crop harvest. Crops that are cultivated on mechanically worked soils upset the balance and make the soils more acidic. This is the outcome of base cations being eliminated along with crops and the concurrent rise in leaching that occurs from working and disturbing soils (Brady and Weil, 2016; Fageria, 2009).

High-yield crop harvest is the main cause of the rising acidity of the soil. Basic elements including calcium, magnesium, and potassium are absorbed by crops throughout growth in order to meet their nutritional needs. More of these fertilizers that resemble lime are being removed from the field as crop yields rise. Grain has much smaller concentrations of these essential elements than the plant's leaf and stem sections. Soil

acidity is impacted more by the harvesting of high-yielding forages like alfalfa and Bermuda grass than by the harvesting of grains (Fageria and Baligar, 2008; Rengel, 2011).

Land Use Change or Land Cover Changes

Research has demonstrated that changes in land cover or use have a detrimental impact on the characteristics of soil. For instance, the impact of land use systems on various physical and chemical soil qualities was studied by Gebrekidan and Negassa (2006), who found that the sand, silt, and clay fractions were considerably impacted by land use systems. The depth of the soil increased clay but decreased silt and sand. There were notable differences across the land use systems in terms of soil pH, total N, organic carbon, accessible P, exchangeable cations, exchangeable Al, effective cation exchange capacity, and Al saturation. Al saturation rose with soil depth, and while the subsoils showed Al toxicity, the top layers had issues with acidity. Similarly, Chimdi et al. (2012) found that a decrease in the overall porosity of cultivated and grazing land soils relative to forest land soils was caused by a decrease in the distribution of pore sizes and the amount of soil organic matter (SOM) lost, both of which are dependent on the level of soil management methods. In addition, Bore and Bedadi (2015) found that, in comparison to forest soil, the amount of SOM in cultivated and grazed lands has decreased by 42.6 and 76.5%, respectively. Native forest and range area being converted to agricultural land degrades the qualities of the soil. The fertility status of a particular soil type is lowered by such activities, which also result in an increase in bulk density and a decrease in CEC and the amount of soil organic matter (SOM). Additionally, substantial differences in soil parameters and a decrease in productivity might result from changes in land use related to deforestation, continuous farming, overgrazing, and mineral fertilizer (Lemenih et al., 2005; Bore and Bedadi, 2015).

Low Buffer Capacity from Little Clay and Organic Matter

Contact exchange between exchangeable hydrogen on root surfaces and bases in exchangeable form on soils is another source of acidity in soil. Microbial synthesis of sulfuric and nitric acids also takes place in areas where leaching is restricted. The amount of lime needed for acid soil depends on the pH of the soil as well as the buffer, or CEC. The amount of organic matter and clay present affects the buffering, or CEC; the more of these elements there are, the larger the buffer capacity. If acidic, soils having a larger buffer capacity (clayey, peats) require more lime. Coarse-textured soils with minimal or no organic matter will require less lime even if they are acidic since they will have a poor buffer capacity.

Over liming damage could result from the careless use of lime on soil with a coarse texture. Because a substantially higher base saturation was needed to elevate the pH to 6 with montmorillonite than with kaolinite, the link between pH and percent base saturation is crucial for soils representative of 1:1 and 2:1 clay. According to the sum of cations, pH 8.2 CEC method, soils containing 2:1 clays (fine, mixed, and thermic Vertic Hapludults) had to be 80% base saturated in order to achieve the same pH as soils containing 1:1 clay (fine, loamy, siliceous thermic Typic Hapludult) at 40% base saturation (Kamprath and Adams, 2010).

Alumino-Silicate Minerals

The main hydrous oxides found in soils are Al and Fe, which can be found as interlayer in clay mineral structures or as coatings on other mineral particles in amorphous, crystalline, or colloidal forms. As the soil's pH drops, these oxides dissolve into solution and release H+ ions via a process called stepwise hydrolysis, which causes the soil to become even more acidic (Abebe, 2007; Somani et al., 1996). Plant growth is restricted by acidity of the soil not only because of ionic pollutants such as H, Mn, and P, but also because of shortages in P, Mo, Ca, and Mg. It has been established that one of the most frequent reasons for yield decline in acid soils is the toxicity of these components. The toxicity of acid soil is a complicated phenomenon resulting from a multitude of elements that might impact plant growth via several physiological and biochemical routes. Acid soil infertility is closely linked to growth-limiting elements such as Al^{3+}, Mn^{2+}, and low pH (H+ toxicity). Plant growth may be impacted by these toxicity variables alone, in combination, or both (Sanchez, 1977; Somani, 1996).

Effect of Soil Acidity on Plant Nutrient Availability and Crop Yield

The primary source of the negative effects of soil acidity on plant growth and output is phosphorus deficiency, which is brought on by P adhering to colloidal fractions and converting to insoluble Al and/or Fe compounds as well as the toxicity of iron, manganese, and aluminum (Brady and Weil, 2008). It has also been noted that agricultural output in acidic soils is restricted by deficiencies of calcium, magnesium, potassium, and molybdenum. The pH of the soil has a direct bearing on the availability and solubility of critical nutrients for plants (Marschner, 2011).

The pH of the soil has a direct bearing on the availability and solubility of critical nutrients for plants (Marschner, 2011; Somani, 1996). Plant nutrient availability is influenced by the pH of the soil. High soil acidity can have two effects: on the one hand, an oversupply of soluble Al, Mn, and other metallic ions, and a scarcity of accessible Ca, P, and Mo (Agegnehu and Sommer, 2000a; Somani, 1996). Acid soil impairs the movement of soil organisms that plants require to keep healthy and limits the availability of essential nutrients including P, K, Ca, and Mg. An alkaline chemical must be applied to raise the pH of a soil if it is too acidic for plants to develop in a healthy manner.

Crop productivity on acid soils is limited by the acidity of the soil and the resulting reduced availability of nutrients (Bekele and Hofner, 1993; Beyene, 1987; Mamo and Haque, 1991). Due to its high immobility

among the key plant nutrients (Agegnehu and Sommer, 2000b; Sanchez, 1977), phosphate can easily be rendered unavailable to plant roots in soils with pH values below 5.5. Consequently, crop yields in these types of soils are typically very poor. Plants are more able to get P when the pH of the soil is between 5.5 and 7. If the soil reaction is kept within the soil pH range of 5.5 to 7, toxicity and Mn and Fe deficiencies may be prevented; According to Somani (1996), this pH range appears to encourage the most readily available plant nutrients. Since growing crops absorb roughly 0.44-kilogram P ha-1 per day, the amount of P in soil solution required for optimum crop growth is between 0.13 and 1.31 kg P ha-1 (Lawlor, 2004). According to Lawlor (2004), the topsoil layer's labile proportion ranges from 65 to 218 kg P ha-1, which has the potential to replenish soil solution P. Particular adsorption and precipitation reactions cause phosphate sorption, or the removal of orthophosphate from soil solution into solid phases (Sample et al., 1980; Sanchez and Uehara, 1980).

According to Parfitt (1978), precipitation reaction happens when insoluble P compounds develop and precipitate, whereas specific adsorption happens when P anions replace the hydroxyl groups on the surface of Al and Fe oxides as well as hydrous oxides. Al and Fe phosphates may precipitate from soils with very low pH values (≤4.5–5.0), while insoluble calcium phosphates may develop at high pH values (>6.5) (Haynes, 1984).

However, in many cases, the primary controllers of P concentrations in soil solutions are particular adsorption reactions (Parfitt, 1978). Numerous variables, such as pH, the background electrolyte's ionic strength, and anion competition, influence the specific adsorption of P (Barrow, 1984). The crop being grown determines the ideal pH since different crops react differently to acidic soil. For instance, Uchida and Hue (2000) reported that nodules in the roots of food and forage legumes, such beans, peas, and desmodium fodder, allow bacteria to absorb nitrogen from the atmosphere and transform it into a form that the plant can use. For the legumes that need those specific strains of bacteria, a pH of 6 or above is ideal because some strains of the bacteria cannot survive at pH levels lower than 6. While potato plants can grow well at higher pH levels, the ideal soil pH range for potato growth is 5.0 to 5.5 because potato scab disease is more common when soil pH is over 5.5. Conversely, plants with pH levels above 5.5 experience iron (Fe) and magnesium deficits, whereas plants like camelia and azalea thrive exclusively at pH levels below 5.5. For optimal crop yields and nutrient availability, soil pH should be between 6.0 and 7.0. which popular field crops prefer as their range (Duncan, 2002). Legumes can only produce so much due to acidic soil (Fageria et al., 2012). It is currently one of the main things preventing Ethiopia from producing enough faba beans (Endalkachew et al., 2018; Mesfin et al., 2019). While neutral soils with a pH range of 7-8 are thought to be ideal for growing cotton, alfalfa, oats, and cabbage, acid soils are not tolerated by these crops. Soils with a pH of 6-7 are ideal for the growth of wheat, barley, corn, clover, and beans. Since grasses can withstand acidic soils more than legumes can, liming to a pH of 5.5 may regulate acidity without affecting yield.

Conversely, legumes thrive in pH ranges between 6.5 and 7.5 and require more calcium. Millet, sorghum, sweet potatoes, potatoes, tomatoes, flax, tea, rye, carrots, and lupine are among the crops that can withstand acidic soils (Somani, 1996). The main signs of elevated soil acidity that might result in lower yields are poor plant vigor, uneven crop growth, poor legume nodulation, stunted root growth, the persistence of weeds that can withstand acidic conditions, an increase in disease incidence, and aberrant leaf colors (Kang and Juo, 1986; Somani, 1996). Poor plant growth and water use efficiency are likely to result from increased acidity because of nutritional imbalances and deficiencies, as well as induced toxicity from aluminum and magnesium. High Al concentrations also have an impact on plant respiration, cell division, glucose phosphorylation, nitrogen mobilization, and the uptake and translocation of nutrients, particularly the immobilization of P in the roots (Baquy et al., 2017; Fageria and Baligar, 2008). (Fox, 1979; Haynes and Mokolobate, 2001). Even at pH lower than 4, insensitive plant species are not greatly affected by soil acidity, whereas sensitive plant species can be inhibited in their growth at pH 5.5 or lower. Al and Mn toxicity, as well as Ca and Mo insufficiency, exacerbate and frequently outweigh this pH effect (Baquy et al., 2017; Fox, 1979; Somani, 1996). When Al poisoning causes acidity, the roots are frequently the first organs to suffer damage; they become stunted and stubbly. Acid soils can have low levels of immobile nutrients, which stunted roots find difficult to obtain. There is a significant reduction in the plant's capacity to absorb water and nutrients, especially those that are stationary like P (Fox et al., 1979). As a result, plants are vulnerable to both nutritional deficits and drought.

In addition to the common red discolorations linked to P shortage, micronutrient deficiency symptoms are also commonly noted. Furthermore, because Al directly opposes magnesium absorption, magnesium deficiency symptoms serve as a helpful marker for acidity issues (Marschner, 2011). The main cation linked to the acidity of soil is exchangeable Al. The presence of more than 1 mg kg-1 of Al in the soil solution damages the root growth of sensitive crop species. When Al occupies 60% or more of the soil's exchangeable capacity, this frequently occurs. Mn can potentially be harmful since it becomes highly soluble at pH values below 5.5 (Somani, 1996).

Nutrient availability for plants is influenced by the pH of the soil. Excess soluble Al, Mn, and other metallic ions and a lack of accessible Ca, P, and Mo are the results of excessive soil acidity (Agegnehu and Sommer, 2000a). The movement of soil organisms that plants require for good health is impacted by acid soil, which also restricts the availability of essential nutrients including P, K, Ca, and Mg.

One of the factors limiting crop productivity in acid soils is the acidity of the soil and the resulting reduced nutrient availability. Since phosphate is the most immobile of the primary plant nutrients, it can easily be rendered unavailable to plant roots in soils with pH values below 5.5 (Agegnehu and Sommer, 2000b). Crop yields in these types of soils are often quite poor. P fixation is low and P availability to plants is higher in soil pH ranges of 5.5 to 7. If the soil reaction is kept within the pH range of 5.5 to 7, which appears to encourage the readiest availability of plant nutrients, toxicity and deficiencies of Fe and Mn may be avoided.

Given that developing crops absorb roughly 0.44 kilogram of P ha-1 per day, the ideal range of P concentrations in soil solutions for crop growth is 0.13 to 1.31 kg P ha-1 (Lawlor, 2004). Between 65 and 218 kg P ha-1 make up the labile fraction in the topsoil layer, this has the potential to replenish soil solution P (Lawlor, 2004).

Soil Acidity Management

The goal of managing acidic soils should be to increase their potential for production by adding amendments to neutralize the acidity and adjusting farming techniques to provide the highest possible crop yields. Maintaining the ideal availability of soil nutrients and reducing potential toxicities depend greatly on the acid/alkali balance (measured by pH) of the soil. For instance, at very low pH levels, Ca levels can be low, P can become unavailable, and Al can become more soluble and absorbed by roots, making it poisonous. Due to their lock-up as insoluble hydroxides and carbonates at high pH, Fe and other micronutrients (apart from Mo) become inaccessible (Slattery and Hollier, 2002).

Liming

The process of liming involves adding materials rich in calcium and magnesium to soil. These materials might take several forms, such as hydrated lime, chalk, marl, or limestone. When multicropping with acid-sensitive crops is used in highly acidic soil, it is a favorable approach. When lime is at its purest, it mostly consists of calcium. Due to its basic nature, calcium carbonate neutralizes acid (Edmeades et al., 2003).

Lime enhances Ca and Mg availability and base saturation. By deactivating the reactive components, fixation of P and Mo is decreased. Root growth is encouraged and nutrient uptake is enhanced as a result of the correction of toxicity caused by excess soluble Al, Fe, and Mn. According to Fargeria and Baligar (2008), liming has several benefits for legumes, including increased microbial activity, improved N fixation, and enhanced N mineralization. The bioavailability of micronutrients, such as zinc, copper, iron, manganese, and boron, can be significantly decreased by overliming, albeit this effect is pH-pH-dependent (Fageria and Baligar, 2008).

Plant nutrient deficits, especially in Fe, may result from this. The primary way that soil acidity limits or lowers crop output is by hindering root growth, which lowers nutrient and water intake (Marschner, 2011). Acidity of the soil changes available soil nutrients into unavailable forms. Acidity of the soil also affects basiccations, which are necessary for crop growth and development and include calcium, potassium, magnesium, and several micronutrients. There are times when soil acidity causes a crop to fail completely, and the amount of damage that acidity causes vary from place to location based on a number of factors.

Liming therefore has the following key effects: it raises pH, accessible P, exchangeable cations, percent base saturation, and the growth density and length of root hairs for uptake of P. It also increases available P by inactivation or precipitation of exchangeable and soluble Al and Fe hydroxides (Marschner, 2011). The acidity of the soil can be readily adjusted by introducing basic materials to neutralize the acid present or by liming the soil.

Dolomitic or calcitic agricultural limestone is the most affordable and manageable liming material. Agricultural limestone needs to be very finely crushed in order to be extensively mixed with the soil and given time to react with the acidity of the soil because these products are naturally occurring and are somewhat insoluble in water. 90% of calcitic limestone is composed of $CaCO_3$ (calcium carbonate). Rocks with a mixture of magnesium and calcium carbonates ($CaCO_3$+$MgCO_3$) are used to make dolomitic limestone.

Burnt lime (CaO), hydrated lime ($Ca(OH)_2$), and wood ashes are additional liming ingredients that are less commonly utilized (Rengel, 2011).Agegnehu et al. (2006) report that the application of lime at rates of 1, 3, and 5 t ha-1 produced a substantial linear response with mean advantages in faba bean seed production of 45, 77, and 81% over the control. According to Desalegn et al. (2017), applying 0.55, 1.1, 1.65, and 2.2 t lime ha-1 raised soil pH by 0.48, 0.71, 0.85, and 1.1 units and lowered Al^{3+} by 0.88, 1.11, 1.20, and 1.19 mill equivalents per 100 g of soil. Additionally, Agegnehu et al. (2006) reported that when the lime rate increased, the pH of the soil constantly rose from 4.37 to 5.91. On the other hand, because lime was applied, the exchangeable acidity decreased dramatically from 1.32 to 0.12 cmol (+) kg-1. Increases in yield were directly correlated with soil pH levels and inversely correlated with exchangeable acidity; that is, yield rose in tandem with pH increases, whereas faba bean yield increased in response to decreases in exchangeable acidity and vice versa. Additionally, it was shown that the ideal range for legume seed yields was between 5.7 and 7.2 pH values. Moreover, adding lime to soils with pH values below 5.4 enhanced pea yields by 30%.

Complimentary Management Strategies/Using Acid Tolerant Crop Varieties

Using tolerant species/varieties of pasture and crops can lessen the effects of soil acidity if the pH of the soil is low. Without liming treatment, the soil will continue to get more acidic, therefore this is not a long-term fix. The rate of soil acidity can be slowed down by a variety of management techniques. In places with significant

rainfall, controlling the use of nitrogen fertilizer is the most crucial strategy to prevent nitrate leaching. Hay that has been cut can be fed back into paddocks to decrease product export. It will also be beneficial to use less acidifying crop rotation choices; for example, swap out legume hay for a pasture or crop that is less acidifying (Bolland et al., 2004).

The majority of economically significant plant species are thought to be resistant to acidic soil conditions. Since many of them originated in areas with acid soil, it is possible that adaptation to soil limitations occurred during the evolutionary process. Certain species' variations can withstand acidic soil, even while the species doesn't survive it overall. Plant tolerance to high concentrations of Al or Mn, as well as to shortages in Ca, Mg, P, and other elements, is measured quantitatively.

There has been significant variance observed in the tolerance of different species to Al and Mn, as well as between genotypes within the same species. Practically speaking, it is crucial to choose species or types that do well at high Al saturation levels and require a small amount of lime. Barley is typically produced on Nitisols, which have low soil pH, in Ethiopia's highlands. This indicates that barley is already acclimated to acidic soil. On light of this, five released barley cultivars were assessed in acidic soils at Endibir in both limed and unlimed conditions. The barley varieties Dimtu and HB-42 fared well in limed conditions, that is to say.

yield increases above matching yields of the same barley kinds under unlimed conditions of 366 and 327%, respectively, were noted. Whereas the corresponding yields of the same barley types obtained under limed conditions were 48 and 49%, respectively, the barley varieties HB-1307 and Ardu performed better under unlimed conditions (Kochian et al., 2004).

Addition of Organic Fertilizers to Acidic Soils

Crop leftovers and farmyard manure (FYM) are two examples of organic plant nutrition sources that can improve the chemical and physical characteristics of soils. In order to recycle plant nutrients, for instance, Lal (2009) stated that crop residues must be returned to the soil as amendments. This results in 118 million mg of N, P, and K in residues produced annually worldwide (83.5% of global fertilizer usage), or 20–60 kg of N, P, K, and Ca per mg of crop residues.

A spectrum of organic acids that can form stable complexes with Al and Fe and block the P retention sites are released by applying FYM to acid soils where P fixation is a issue. This improves the availability and usage efficiency of P (Agegnehu and Amede, 2017). On the basis of cation exchange between root surfaces and soil colloids, manure's beneficial effects on crop yields have been described. It has been successful in lowering the phytotoxic levels of Al in acidic soils by adding organic fertilizers, leading to an increase in yield.

The main processes that are assumed to be in charge of these benefits are the direct neutralization of Al from the increase in pH brought on by the organic matter or the development of organo-Al complexes that make the Al less poisonous. Agegnehu and Amede (2017) suggest that an organic source such as agricultural wastes, compost, manures, and biochar could be used in place of lime. The authors showed that, after accounting for the acidity created during the oxidation of the N in the material, organic sources elevate pH and precipitate Al in direct proportion to their basic cation or ash alkalinity. In contrast to rice husk biochar, cacao shell biochar was reported by Cornelissen et al. (2018) to have a higher pH (9.8 vs. 8.4), CEC (197 vs. 20 cmol kg-1), and acid neutralizing capability (217 vs. 45 cmol kg-1). As a result, it had a stronger potential for liming.

Additionally, Haile and Boke (2011) observed that, in comparison to applying NP fertilizer alone, the combined application of FYM and NP fertilizer on the acid soil of Chencha, southern Ethiopia, considerably boosted potato tuber output and some soil chemical parameters. Crop yields in tropical climates typically diminish with time, in part because of a decrease in the amounts of exchangeable bases connected to the acidity of the upper soil layers. In addition to increasing crop yields, managing acidic soils with integrated soil fertility and plant nutrition management also improves the chemical composition of the soil. A sustained rise in SOM and nutritional content can be achieved with the regular application of organic wastes.

Haynes and Mokolobate (2001) state that the concentrations of exchangeable and soluble Al tend to decrease as a result of Al complexation with the recently generated organic matter. P is produced during the breakdown of organic wastes and can adsorb to oxide surfaces. This may increase the availability of P by reducing the amount of P that is subsequently added through adsorption. These processes have the practical consequence of allowing organic residues to be strategically employed to lower the rates of lime and fertilizer P needed for the best crop yield on acidic, P-fixing soils.

Agegnehu and Bekele (2005b) discovered that, in comparison to the control, the treatment of 4 and 8 t FYM ha-1 with 26 kg P ha-1 on acid Nitisols of Holetta, Ethiopia, improved the yield of faba bean seeds by 97 and 104%, respectively. Soil pH increased from 4.5 to 5.0, N from 0.09 to 0.15%, P from 4.2 to 6.0 mg kg-1, and K, Ca, and Mg from 1.25 to 1.45, 4.77-7.29, and 0.83-1.69 cmol (+) kg-1, respectively, at the same rates.

CONCLUSION

Acidity in soil is a naturally occurring process that arises from a combination of certain climatic, topographical, vegetative, parent material, and rainfall circumstances. It is the primary cause of agricultural productivity limitations and interruptions in many regions of the world, including Ethiopia. Ethiopia's highland regions are experiencing an increase in soil acidity issues. Crop productivity is primarily limited by acidity of the soil and the resulting inadequate availability of nutrients. One of the physiological properties of the soil solution that is expressed in terms of pH is soil response, which shows

whether the soil is neutral, acidic, or alkaline. It has an important impact on a variety of soil characteristics, such as the availability of nutrients, biological activity, and physical state of the soil. Soil acidity usually has negative impacts when the pH of the soil drops below 4.5. The phytotoxicity of aluminum (Al) and deficits in phosphorus (P), calcium (Ca), and magnesium (Mg) are the two main reasons that restrict the fertility of acid soils.

A key component of agricultural sustainability is the preservation of soil quality and the use of sustainable soil management techniques. Lime is a potentially better alternative for sustainable soil management than other options since it improves the habitat for leguminous plants and related microbes and increases the concentration of vital minerals by boosting soil fertility and health. This widely used technique raises crop yields on acidic soils by raising the pH of the soil and causing exchangeable aluminum to precipitate.

It has been shown that the best crop performance in acid soils requires liming the soil to lessen soil acidity and lower phytotoxic levels of Mn and Al. But lime treatment should be viewed as a strategy to raise the pH of the soil in order to maximize nutrient availability for the best possible plant growth and yield; it is not a means to an end in and of itself to reach potential output. The best rates of inorganic and organic fertilizers, especially P and K fertilizers, should be used in conjunction with liming. Furthermore, it's important to pinpoint the regions where applying lime significantly improves crop productivity.

To elevate soil pH to a level appropriate for maximum nutrient availability, plant growth, and crop output, liming should be viewed as a soil amendment. Generally speaking, it is extremely important from a practical standpoint to utilize all of the resources at hand, including crop species and acid-tolerant varieties that enhance and maintain soil and agricultural output. All things considered, acid soil management must prioritize strategic research, combining enhanced crop types with soil and water management to create environmentally benign prototype technologies for sustained food production within the parameters of sensible socioeconomic and regulatory concerns.

The solutions for these issues include lime and fertilizers with inorganic phosphate. Unfortunately, our nation's farmers do not use them frequently due to rising costs and unavailability when needed. For this reason, the government need to focus on the availability of where it is prudently required. Ethiopia's declining soil fertility can be attributed to poor nutrient inputs, soil erosion, and an existing nutrient deficit. Integrated soil fertility management is the greatest solution to these issues. When alternative methods of soil amendment are not easily implemented, genotypes that are acclimated to acid soil conditions can also be grown to address issues with soil acidity. Liming, the application of integrated soil fertility management, and crop varieties resistant to Al toxicity are therefore the mechanisms employed for management of acid soils and should be proven and popularized on farmers' fields for sustainable agricultural systems within Ethiopian small-scale farming.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Abate, E.; Hussein, S.; Laing, M.; Mengistu, F. 2017. Soil acidity under multiple land-uses: Assessment of perceived causes and indicators, and nutrient dynamics in small-holders' mixed-farming system of northwest Ethiopia. Acta Agric. Scand. Sect. B Soil Plant Sci., 67, 134–147.

Abdenna Deressa, Bikila Bote, and Hirpa Legesse. 2013. Evaluation of Soil Cations in Agricultural Soils of East Wollega Zone in South Western Ethiopia. *Sciences, Technology and Arts Research Journal*, **2**(1): 10-17

Abdenna Deressa, Negassa Chewaka and Tilahun Geleto 2007. Inventory of Soil Acidity Status in Crop Lands of Central and Western Ethiopia. In: Utilization of diversity in land use systems: Sustainable and organic approaches to meet human needs. A paper presented on Tropentag, October 9-11, Witzenhausen, Germany.

Abdissa Bekela. 2019. Evaluation of soil acidity and effects of amendments on selected soil properties and yield of maize (*Zea Mays* l.) In Ebantu district, Western Highlands of Ethiopia. Phd Dissertation. Haramaya University.

Abebe Z. and Tolera A. 2014. Yield response of faba bean to fertilizer rate, rhizobium inoculation and lime rate at Gedo highland, western Ethiopia. *Global Journal of Crop, Soil Science and Plant Breeding*, **2**(1):134- 139.

Abebe, M. 2007. "Nature and management of acid soils in Ethiopia," Haramaya University, Haramaya, Ethiopia.

Abebe, M. 1998. "Nature and management of Ethiopian soils," Alamaya University of Agriculture, Alemaya, Ethiopia.

Abreha Kidanemariam, HelufGebrekidan, Tekalign Mamo, KindieTesfaye, 2013. Wheat Crop Response to Liming Materials and N and P Fertilizers in Acidic Soils of Tsegede Highlands, Northern Ethiopia. *Agriculture, Forestry and Fisheries*. **2**(3): 126 -135.

Abu Regasa Gemada 2021. Soil Acidity Challenges to Crop Production in Ethiopian Highlands and Management Strategic Options for Mitigating Soil Acidity for Enhancing Crop Productivity. *Agriculture, Forestry and Fisheries*. 10(6):245-261. doi: 10.11648/j.aff.20211006.15

Achalu Chimdi, Heluf Gebrekidan, Kibebew Kibret, and Abi Tadesse. 2012. Effects of Liming on Acidity-Related Chemical Properties of Soils of Different

Land Use Systems in Western Oromia, Ethiopia. *World Journal of Agricultural Sciences*, **8**(6): 560-567.

Achalu Cimidi, Heluf Gebrekidan, Kibebew Kibret, Abi Tadesse. 2012. Response of barley to liming of acid soils collected from different land use systems of Western Oromia, Ethiopia. *J. Bio. div. Environ. Sci.* **2**(7):1-13.

Agegnehu G, Yirga C, Erkossa T. 2019. Soil acidity management. Ethiopian Institute of Agricultural Research (EIAR) Addis Ababa, Ethiopia pp. 21.

Agegnehu, G., Fikre, A., and Tadesse, A. 2006. Cropping Systems, Soil Fertility and Crop ManagementResearch on Food Legumes in the Central Highlands of Ethiopia. In "A Reviewof Major Achievements of a Decade" (K. Ali, G. Keneni, S. Ahmed, R. S. Malhotra, S. Beniwal and K. Makkouk, eds.), pp. 135-145. ICARDA, Addis Ababa, Ethiopia.

Agegnehu, G., and Amede, T. 2017. Integrated soil fertility and plant nutrient management in tropicalagro-ecosystems: A review. *Pedosphere* **27:** 662-680.

Agegnehu, G., and Bekele, T. 2005b. Phosphorus ferilizer and farmyard manure effects on the growth and yield of Faba Bean and some soil chemical properties in acidic nitisols of the central highlands of Ethiopia. *Ethiop. J. Nat. Resources*. **7:** 23-39.

Agegnehu, G., and Sommer, K. 2000b. Optimization of the efficiency of phosphate fertilizers in acidicferralitic soils of the humid tropics. Ethiop. *J. Nat. Resources* **2:** 63-77.

Agegnehu, G., and Sommer, K. 2000a. Optimization of the efficiency of phosphate fertilizers in acidicferralitic soils of the humid tropics. *Ethiopian Journal of Natural Resources* **2:** 63-77.

Agegnehu, G., and Sommer, K. 2000b. Optimization of the efficiency of phosphate fertilizers in acidicferralitic soils of the humid tropics. *Ethiop. J. Nat. Resources* **2:** 63-77.

Agegnehu, G.; Amede, T. 2017. Integrated soil fertility and plant nutrient management in tropical agro-ecosystems: A review. *Pedosphere* **27**: 662–680.

Agegnehu, G.; Yirga, C.; Erkossa, T. 2019. Soil Acidity Management; Ethiopian Institute of Agricultural Research (EIAR): Addis Ababa, Ethiopia.

Akhtar Schuster, M., Thomas, R. J., Stringer, L. C., Chasek, P., and Seely, M. 2011. Improving the enabling environment to combat land degradation: Institutional, financial, legal and science-policy challenges and solutions. *Land Degradation and Development* **22:** 299-312.

Alemu G, Desalegn T, Debele T, Adela A, Taye G, Yirga C. 2017. Effect of lime and phosphorus fertilizer on acid soil properties and barley grain yield at Bedi in western Ethiopia. *African Journal of Agricultural Research*. **12**: 3005–3012.

ATA 2014. Soil Fertility Mapping and Fertilizer blending. Agricultural Transformation Agency (ATA), Addis Ababa, Ethiopia.

Aye, N.S., Sale, P.W.G. & Tang, C. 2016. The impact of long-term liming on soil organic carbon and aggregate stability in low-input acid soils. *Biology and Fertility of Soils*, **52**: 697-709. https://doi.org/10.1007/s00374-016-1111-y

Baquy, M., Li, J. Y., Xu, C. Y., Mehmood, K., and Xu, R. K. 2017. Determination of critical pH and Al concentration of acidic Ultisols for wheat and canola crops. *Solid Earth* **8**, 149-159

Barak, P.; Jobe, B.O.; Krueger, A.R.; Peterson, L.A.; Laird, D.A. 2010. Effects of long-term soil acidification due to nitrogen fertilizer inputs in Wisconsin. Plant Soil 1997, 197, 61–69. Guo, J.H.; Liu, X.J.; Zhang, Y.; Shen, J.L.; Han, W.X.; Zhang, W.F.; Christie, P.; Goulding, K.W.T.; Vitousek, P.M.; Zhang, F.S. Significant acidification in major Chinese croplands. Science **327:** 1008–1010.

Barber, S. A. 2010. Liming materials and practices. In ''Soil Acidity and Liming'' (F. Adams, Ed.), 2nd Ed. pp. 171–209. ASA-CSSA-SSSA, Madison, Wisconsin.

Behera, S. K., and Shukla, A. K. 2015. Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content and exchangeable potassium, calcium and magnesium in some cropped acid soils of India. *Land Degrad. Dev*. **26:** 71-79.

Bolan, N.S., Adriano, D.C. & Curtin, D. 2003. Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. *Advances in Agronomy*, **78**: 215-272. https://doi.org/10.1016/S0065-2113(02)78006-1

Bolland M, Gazey C, Miller A, Gartner D and Roche J 2004. Department of Agriculture and Food, Western Australia Bulletin 4602. (online)

Bordeleau, L.M. and Prevost, D. 1994. Nodulation and nitrogen fixation in extreme environments. *Plant and Soil*, **161**(1):115-125.

Bore, G., and Bedadi, B. 2015. Impacts of land use types on selected soil physico-chemical properties of Loma Woreda, Dawuro zone, southern Ethiopia. *Sci. Technol. Arts Res. J.* **4**, 40-48.

Bore, G., and Bedadi, B. 2016. Response Wheat (*Triticum aestivum* L.) to Liming of Acid Soils under Different Land Use Systems of Loma Woreda, Dawuro Zone, Southern Ethiopia. *Journal of Environment and Earth Science* **6,** 99-108.

Brady, N., and Weil, R. 2016. "The nature and properties of soils," Pearson Education, Columbus, EUA.

Caires, E.F., Joris, H.A.W. & Churka, S. 2011. Long-term effects of lime and gypsum additions no no-till corn and soybean yield and soil chemical

properties in southern Brazil. *Soil Use and Management*, 27: 45-53. https://doi.org/10.1111/j.1475-2743.2010.00310.x

Central Statistical Agency 2019 /20. Agricultural Sample Survey, volume I: Report on Area and Production of major Crops, Private Peasant Holdings, Meher Season. Addis Ababa, Ethiopia

Chimdi, A., Gebrekidan, H., Kibret, K., and Tadesse, A. 2012. Status of selected Physicochemicalproperties of soils under different land use systems of western Oromia, Ethiopia. *J. Biodiv. Environ.Sci*. **2**: 57-71.

Cornelissen, G., Nurida, N. L., Hale, S. E., Martinsen, V., Silvani, L., and Mulder, J. 2018. Fading positive effect of biochar on crop yield and soil acidity during five growth seasons in an Indonesian Ultisol. *Sci. Total Environ*. **634**: 561-568.

CSA (Central Statistics Agency) 2018. The preliminary results of area, production and yield of temporary crops.Statistical Bulletin, Volume 1, Addis Ababa, Ethiopia.

CSA 2015 .The Federal Democratic Republic of Ethiopia Central Statistical Agency report on area and production of major crops. CSA, Addis Ababa

Deressa A, Chewaka N, Geleto T. 2007. Inventory of soil acidity status in crop lands of central and western Ethiopia. Utilization of diversity in land use systems: Sustainable and organic approaches to meet human needs. *Tropentag*. 9–11.

Desalegn, T., Alemu, G., Adella, A., and Debele, T. 2017. Effect of lime and phosphorus fertilizer on Acidsoils and barley (*Hordeum vulgare* L.) performance in the central highlands of *Ethiopia. Exp. Agric*.**53**: 432-444.

ebede, F.; Yamoah, C. 2009. Soil fertility status and numass fertilizer recommendation of typic hapluusterts in the northern highlands of Ethiopia. *World Appl. Sci. J.*, **6**: 1473–1480.

Edmeades, D., Ridley, A., and Rengel, Z. 2003. Handbook of soil acidity. Handbook of soil acidity.

Elias, E. 2017. Characteristics of Nitisol profiles as affected by land use type and slope class in some Ethiopian highlands. Environ. Syst. Res., **6**: 20.

Endalkachew F., Kibebew K., Asmare M. and Bobe B. 2018. Yield of faba bean (*Vicia faba* L.) as affected by lime, mineral P, farmyard manure, compost and rhizobium in acid soil of lay gayint district, northwestern highlands of Ethiopia. *Agriculture and Food Security*, **7**(16):1-11.

Ethio SIS. 2014. Soil fertility mapping and fertilizer blending. Agricultural Transformation Agency (ATA) Report, Ethiopia soil information system (Ethio SIS). Ministry of Agriculture, Addis Ababa.

Ethio, S I S. 2014. "Tentative List of Fertilizers Required in Oromia Region for 124 Surveyed Woredas by Ethiopian Soil Information System." MoA, ATA. Addis Ababa, Ethiopia.

EthioSIS (Ethiopian Soil Information System), 2014. Towards improved fertilizer recommendations in Ethiopia-Nutrient indices for categorization of fertilizer blends from EthioSISworeda soil inventory data. Addis Ababa, Ethiopia.

Eyasu Elias, 2016. Soil of Ethiopian Highlands: Geomorphology and properties.CASCAPE Project, ALTERA, Wageningen University and Research Centre (Wageningen UR). The Netherlands.385pp

Fageria N, Baligar V, Li Y. 2008. The role of nutrient efficient plants in improving crop yields in the twenty first century. *Journal of plant nutrition*.; **31**: 1121–1157.

Fageria, N., and Baligar, V. 2008. Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Adv. Agron*. **99**: 345-399.

Fageria, N. K. 2009. "The use of nutrients in crop plants," CRC Press: Taylor and Francis Group, USA.

Fageria, N. K., and Nascente, A. S. 2014. Management of soil acidity of South American soils for sustainable crop production. *Adv. Agron*. **128**: 221-275.

Fageria, N. K., Baligar, V.C., Melo, L. C. and de Oliveira, J. P. 2012. Differential Soil Acidity Tolerance of Dry Bean Genotypes. Communications in Soil Science and Plant *Analysis* **43**(11): 1523-153.

Fageria, N.K. & Baligar, V.C. 2008. Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Advances in Agronomy*, **99**: 345-399. https://doi.org/10.1016/S0065- 2113(08)00407-0

Fanuel Laekemariam and Kibebew Kibret. 2021. Extent, Distribution, and Causes of Soil Acidity under Subsistence Farming System and Lime Recommendation: The Case in Wolaita, Southern Ethiopia.; Article ID 5556563, 9 pages

FAO. 2015. Declaration of the world summit on food security, Rome. www.fao.org/wsfs/world-summit.en.

FAO. 2017. Voluntary Guidelines for Sustainable Soil Management. Rome, Italy, Food and Agriculture Organization of the United Nations.

Farina, M. P. W. 1997. Management of subsoil acidity in environments outside the humid tropics. p. 179–190. In A.C. Moniz et al. (ed.) Plant–soil interactions at low pH: Sustainable agriculture and forestry production. Brazilian Soil Sci. Soc., Campinas, Brazil [48]

Farina, M. P. W., Channon, P., and Thibaud, G. R. 2000. A Comparison of strategies for ameliorating

subsoil acidity: II. Long-term soil effects. Soil *Sci. Soc. Am. J.* **64**: 652–658.

G. Y. Wendimu, 2021. “Challenges and prospects of Ethiopian Agriculture,” *Cogent Food and Agriculture*, vol. 7, p. 1923619,

Gebrekidan, H., and Negassa, W. 2006. Inmpact of land use and management practices on chemical properties of some soils of Bako area, Western Ethiopia. *Ethiop. J. Nat. Resources*. **8**: 177-197.

Getachew Agegnehu and Tilahun Amede. 2017. Integrated soil fertility and plant nutrient management in tropical agro-ecosystems: A review. *Pedosphere*, **27**(4): 662–680

Getachew Agegnehu, Chilot Yirga, andTeklu Erkossa. 2019. Soil Acidity Management. Ethiopian Institute of Agricultural Research (EIAR). Addis Ababa, Ethiopia.

Guo, J. H., Liu, X. J., Zhang, Y., Shen, J. L., Han, W. X., Zhang, W. F., Christie, P., Goulding, K. W. T.,Vitousek, P. M., and Zhang, F. S. 2010. Significant Acidification in Major Chinese *Croplands. Science* **327**: 1008-1010.

Gurmessa B. 2020. Soil acidity challenges and the significance of liming and organic amendments in tropical agricultural lands with reference to Ethiopia. *Environment, Development and Sustainability*. 1–23.

Habtamu Admas Desta. 2015. Reclamation of phosphorus fixation by organic matter in acidic soils (Review): *Global Journal of Agriculture and Agricultural Sciences*, **3**(6); 271 -278.

Haile, H., Asefa, S., Regassa, A., Demssie, W., Kassie, K., and Gebrie, S. 2017. Extension manual for acid soil management (unpublished report). (A. T. A. (ATA), ed.), Addis Ababa, Ethiopia.

Haile, W., and Boke, S. (2011). Response of Irish potato (Solanum tuberosum) to the application ofpotassium at acidic soils of Chencha, Southern Ethiopia. *Int. J. Agric. Biol*. **13**: 595-598.

Haynes, R., and Mokolobate, M. 2001. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. *Nutr. Cycl. Agroecosyst*. **59**: 47-63.

Haynes, R., and Naidu, R. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutr. Cycl. Agroecosyst*. **51**: 123-137.

Hede, A.R., B. Skovmand and J. Lopez-Cesati, 2001. Acid Soils and Aluminum Toxicity. In: Reynolds, M.P., Ortiz-Monasterio, J.I and McNab, A (eds.). Application of Physiology in Wheat Breeding, Mexico, D.F.: CIMMYT.

Hengl T, Leenaars JGB, Shepherd KD, Walsh MG, Heuvelink GBM, Mamo T, Tilahun H, Berkhout E, Cooper M, Fegraus E, Wheeler I, Kwabena NA 2017. Soil nutrient maps of Sub-Saharan Africa: assessment of soil nutrient content at 250 m spatial resolution using machine learning. *Nutr Cycl Agroecosyst* **109**:107–102

Holland, J.E., Bennett, A.E., Newton, A.C., White, P.J., McKenzie, B.M., George, T.S., Pakeman, R.J., Bailey, J.S., Fornara, D.A. & Hayes, R.C. 2018. Liming impacts on soils, crops and biodiversity in the UK: a review. *Science of the Total Environment*, **610-611**: 316-332. https://doi.org/10.1016/j.scitotenv.2017.08.020

International Food and Policy Research Institute (IRPRI). 2010. Fertilizer and Soil Fertility Potential in Ethiopia. Constraints and opportunities for enhancing the system. Working Paper.42pp

Junquan, Z., Michalk, D., Yifei, W., Kemp, D., Guozhen, D., and Nicol, H. 2007. Effect of phosphorus, potassium and lime application on pasture in acid soil in Yunnan Province, China. *New Zealand J. Agric. Res*. **50**: 523-535.

Kamprath, E. J., and Adams, F. 2010. Soil acidity and liming. In “Century of soil science”, pp. 103-107. Soil Science Society of North Carolina, North Carolina,USA.

Kassaye Gurebiyaw and Abay Gelanew 2019. Soil degradation extent and dynamics of soil fertility improvement technologies in Majete Watershed, North Ethiopia. *Journal of Soil Science Environmental Management* **10**(3):39–45.

Kisinyo, P.O., Gudu, S.O., Othieno, C.O., Okalebo, J.R. and Opala, P.A. 2012. Effects of lime, phosphorus and rhizobia on Sesbania sesban performance in a Western Kenyan acid soil. *African Journal of Agricultural Research*, **7**(18): 2800-2809.

Kochian L.V., M. A. Pineros, J. Liu and J.V. Magalhae, 2015. Plant Adaptation to Acid Soils: The Molecular Basis for Crop Aluminum Resistance. *Annual Review of Plant Biology*, **66**:571–598.

Kochian, L. V., Hoekenga, O. A., and Pineros, M. A. 2004. How do crop plants tolerate acid soils?Mechanisms of aluminum tolerance and phosphorous efficiency. *Annu. Rev. Plant Biol*. **55**: 459-493

Krug, E. C., and Frink, C. R. 1983. Acid rain on acid soil: a new perspective. *Science* **221**: 520-525.

Laekemariam. F, K. Kibret, T. Mamo, and E. Karltun, 2016. “Physiographical characteristics of agricultural land and farmers’ soil fertility management practice in Wolaita Zone, Southern Ethiopia,” Environmental System Research, vol. 5, p. 24, 2016.

Lal, R. 2009. Soils and food sufficiency: A review. In “Sustainable agriculture”, pp. 25-49. Springer.

Lal, R. 2015. Restoring soil quality to mitigate soil degradation. *Sustainability* **7**: 5875-5895.

Lawlor, D. 2004. Mengel, K. and Kirkby, EA Principles of plant nutrition. Oxford University Press.

Lemenih, M., Karltun, E., and Olsson, M. 2005. Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia. *Agric. Ecosyst. Environ*. **105**: 373-386

Li, S., Duan, Y., Guo, T., Zhang, P., He, P., Johnston, A., and Shcherbakov, A. 2015. Potassium management in potato production in Northwest region of China. *Field Crops Research* **174**: 48-54.

Lukin VV, Epplin FM. 2003. Optimal frequency and quantity of agricultural lime applications. *Agricultural systems*. **76**: 949–967.

Lulu M, Lemma B, Melese A. 2020. Soil organic carbon and nutrients in smallholding land uses in southern Ethiopia. *Journal of Plant Nutrition and Soil Science*. **183**: 69–79.

M. B. Hossain, M. H. R. Khan, S. Khanom, and S. A. 2021. Shahid Akhtar Hossain, "Amelioration of soil acidity by the application of maize straw ash in mixed soil," *Dhaka University Journal of Biological Sciences*, **30**(2): 207–219, 2021.

Marschner, H. 2011. "Marschner's mineral nutrition of higher plants," Academic press, London.

Marschner, P., 2012. Mineral Nutrition of Higher Plants (3rd eds.) Acadamic Press Elsevier Ltd., United States of America. 668p.

McCauley CO-R A. Jones. Soil pH and organic matter: Nutrient management. Montana State University; 2017 pp. 1–16. Report No.:8.

Mesfin Abebe. 2007. Nature and management of acid soil in Ethiopia. Haramaya University. Haramaya, Ethiopia. 99pp

Mesfin T. 2019. Genotype x Location x Management and Genetic Variability of Faba Bean (Vicia faba L.) Genotypes Based on Agro-Morphology Traits. MSc Thesis, Haramaya University, Haramaya, Ethiopia.

Mokolobate, M.S., Haynes, R.J., 2002. Comparative liming effect of four organic residues applied to an acid soil. *Biology and Fertility of Soil* **35**(2): 79-85.

Paradelo, R., Virto, I. & Chenu, C. 2015. Net effect of liming on soil organic carbon stocks: a review. *Agriculture, Ecosystems and Environment*, **202**: 98-107. https://doi.org/10.1016/j.agee.2015.01.005

Parfitt, R. L. 1978. Anion adsorption by soils and soil minerals. *Adv. Agron*. **20**: 323-359.

Paul, E. A. 2014. "Soil microbiology, ecology and biochemistry," Third/Ed. Academic press, Elsevier Inc., London, UK.

Pilbeam, D. J., and Morley, P. S. 2007. Calcium. Hand book of plant nutrition. In: Barker, A.V., Pilbeam, D.J. (eds.). CRC: Taylor and Francis, New York, pp. 121-144

Poschenrieder, C., Gunsé, B., Corrales, I., and Barceló, J. 2008. A glance into aluminum toxicity and resistance in plants. *Sci. Total Environ*. **400**: 356-368.

R. Alvarez, A. Gimenez, F. Pagnanini et al., 2020. "Soil acidity in the Argentine Pampas: effects of land use and management," *Soil and Tillage Research*, vol. 196, Article ID 104434, 2020.

Regassa H, Agegnehu G. 2011. Potentials and limitations of acid soils in the highlands of Ethiopia: A review. Barley research and development in Ethiopia. 103.

Regassa, H., and Agegnehu, G. 2011. Potentials and limitations of acid soils in the highlands of Ethiopia: a review. In "Barley research and development in Ethiopia" (B. Mulatu and S. Grando, eds.), pp. 103- 112. ICARDA, Aleppo, Syria.

Rengel, Z. 2011. Soil pH, soil health and climate change. In "Soil health and climate change", pp. 69-85. Springer.

Robertson, G.P. and Swinton, S.M. 2005. Reconciling agricultural productivity and enviromental integrity: a grand challenge for agricultural. *Frontiers in Ecology and Environment*, **3**: 38-46.

Sample, E., Soper, R., and Racz, G. 1980. Reactions of phosphate fertilizers in soils. The role of phosphorus in agriculture, 263-310.

Sanchez, P. A., and Uehara, G. 1980. Management considerations for acid soils with high phosphorus fixation capacity. The role of phosphorus in agriculture, 471-514.

Sanchez, P.A. and Salinas, J.G. 1981. Low input technology for managing Oxisols and Ultisols in Tropical America. *Journal of Advanced Agronomy*, **34**:279-406.

Shainberg, I., Sumner, M. E., Miller, W. P., Farina, M. P. W., Pavan, M. A., and M.V., F. 1989. Use of gypsum on soils: A review. *Adv. Soil Sci*. **9**: 1-111.

Slattery B, Hollier C. 2002. The Impact of Acid Soils in Victoria. Report for the Department of Natural Resources and Environment, Goulburn Broken Catchment Management Authority, North East Catchment Management Authority. Department of Natural Resources and Environment, Rutherglen Research Institute.

Somani, L., Totawat, K., and Sharma, R. A. 1996. "Liming technology for acid soils," Agrotech Publishing Academy, Udaipur, India.

Sumner, M. E., and Noble, A. D. 2003. Soil acidification: The world story. In ''Handbook of Soil Acidity'' (Z. Rengel, Ed.), pp. 1–28. Marcel Dekker, New York.

Tadesse, G. 2001. Land Degradation: A challenge to Ethiopia. Environ. Manage. **27**: 815-824.

Tafesse, S.; Braam, C.; van Mierlo, B.; Lemaga, B.; Struik, P.C. 2021. Association between Soil Acidity and Bacterial Wilt Occurrence in Potato Production in Ethiopia. *Agronomy*, **11**: 1541. https://doi.org/ 10.3390/agronomy11081541

Takala B. 2019. Soil acidity and its management options in western Ethiopia.

Tamene Lulseged; Amede Tilahun; Kihara J; Tibebe Degefi; Schulz S. (eds.). 2017. A review of soil fertility management and crop response to fertilizer application in Ethiopia: towards development of site- and contextspecific fertilizer recommendation. CIAT Publication No. 443. International Center for Tropical Agriculture (CIAT), Addis Ababa, Ethiopia.86p

Taye Bekele. 2007. An overview of acid soils their management in Ethiopia paper presented in the third International Workshop on water management (Wterman) project, September, 19-21: 2007, Haromaya, Ethiopia.

Tegbaru B. 2015. Soil fertility mapping and fertilizer recommendation in Ethiopia: Update of EthioSIS project and status of fertilizer blending plants. Presented at 2nd IPI – MoANR – ATA- Hawassa University Joint Symposium 24th November, Hawassa. https://www.ipipotash.org/udocs/9-soil-fertility-mappingand-fertilizer-recommendation-in-ethiopia.pdf.

Tisdale, S., Nelson, W., Beaton, J., and Havlin, J. 1993. Soil acidity and basicity. Soil Fertility and Fertilizers, 5th ed. Macmillan, New York, 364-404.

Tully K, Sullivan C, Weil R, Sanchez P. 2015The state of soil degradation in sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability*. **7**: 6523–6552.

Vanlauwe B, Descheemaeker K, Giller KE, Huising J, Merckx R, Nziguheba G, Wendt J, Zingore S (2015) Integrated soil fertility management in sub-Saharan Africa: unravelling local adaptation. *SOIL* **1**:491–508

Walker, D. J., Clemente, R., and Bernal, M. P. 2004. Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of Chenopodium album L. in a soil contaminated by pyritic mine waste. *Chemosphere* **57**: 215-224.

Wang, J., Raman, H., Zhang, G. Mendham, N. and Zou, M. 2006. Aluminum tolerance in barely (*Horidium vulgarie* L.): Physiological mechanisms, genetics and screening methods. *Journal of Zhejiang University Science*. **7**: 769-787.

Warner JM, Mann ML, Chamberlin J, Tizale CY 2023. Estimating acid soil effects on selected cereal crop productivities in Ethiopia: Comparing economic cost-effectiveness of lime and fertilizer applications. *PLoS ONE* **18**(1): e0280230. https://doi.org/10.1371/journal. pone.0280230

Warner, J.; Yirga, C.; Gameda, S.; Rashid, S.; Alemu, D. 2016. Soil Acidity Problems in Ethiopia: Magnitude, Current Awareness and Practices, and Policy Actions. In Proceedings of the Research for Ethiopia's Agricultural Policy Presented for EIAR 50th Anniversary, Addis Ababa, Ethiopia, 1 July 2016.

Weil, R.; Brady, N. The Nature and Properties of Soils (Global Edition); Pearson: London, UK, 2016.

World Food Programme 2017. WFP East and Central Africa Horn of Africa Drought Crisis Situation Report #3, 15. http://reliefweb.int/report/somalia/wfp-east-central-africa-horn- africa-drought-crisissituation-report3-15-march-2017 (Accessed 22 December 2019)

Woubshet Demissie, Selamyihun Kidanu, Tolera Abera, and CV Raghavaiah. 2017. Effects of Lime, Blended Fertilizer (NPSB) and Compost on Yield and Yield Attributes of Barley (Hordium Vulgare L.) on Acid Soils of Wolmera District, West Showa, Ethiopia. *Ethiopian.J. Appl. Sci. Technol*. **8**(2): 84-100.

Yirga, C., and Hassan, R. M. 2010. Social costs and incentives for optimal control of soil nutrient depletion in the central highlands of Ethiopia. *Agricultural Systems* **103**: 153-160.

Zeleke, G., Agegnehu, G., Abera, D., and Rashid, S. (2010). Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. (I. F. P. R. I. (IFPRI), ed.), pp. 63, Washington, DC, USA.

ZerihunAbebe, AlemayehuDabessa and EndelkechewWelde-Meskel. 2015. On Farm Yield Responses of Soybean (Glycine max. L (Merrill) to Fertilizer Sources under Different Soil Acidity Status in GobuSayo District, Western Ethiopia. *Journal of Agronomy*, **14**(1): 30-44

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Review Article

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Advancements in Remote Sensing Technologies for Assessing Abiotic Stress in Plants: a Comprehensive Review

T. D. Warik[1], G.S. Pawar[1], G.U. Shinde[3], H.V. Kalpande[1], S.M. Gambhire[1], A.B. Pillewad[1]
[1]Department of Agricultural Botany, College of Agriculture, Parbhani, VNMKV, Parbhani, Maharashtra.
[2]Department of FMPE, VNMKV, Parbhani, Maharashtra.
**Corresponding author e-mail: tejuwarik@gmail.com*
(Received: 03/03/2024; Revised: 25/05/2024; Accepted: 30/05/2024; Published: 30/06/2024)

ABSTRACT
One of the key elements influencing crop production across the globe is abiotic stress. Early detection and corrective action in this regard can help to lessen the effects of stresses on crop growth and output. Recent advances in remote sensing hold a vital role in the early identification of abiotic stress across a broader area with less involvement of money, time, and labour. Remote sensing technology has become an indispensable tool in the field of agriculture, particularly for detecting abiotic stress in plants. This paper reviews the application of remote sensing techniques for the assessment of abiotic stress factors such as drought, flood, salinity, and nutrient deficiency. Furthermore, the review explores the critical aspects of data acquisition, processing, and analysis, underscoring the importance of machine learning and artificial intelligence techniques in enhancing the accuracy of stress detection.
Keywords: abiotic stress, remote sensing techniques, stress detection.

INTRODUCTION

Many environmental elements have an ongoing impact on plants. These include biotic and abiotic stresses. Abiotic stress factors included extreme temperatures (heat, cold, and freezing), too-high or too-low irradiation, water logging, drought, inadequate mineral nutrients in the soil, and excessive soil salinity. Biotic environmental factors are other organisms like symbionts, parasites, pathogens, herbivores, and competitors; and wind, ionizing radiation, or pollutants (Schulze *et al.* 2002). Abiotic stress is defined as any departure from these ideal external circumstances, meaning that there is an excess or variation in the chemical or physical environment that negatively impacts plant growth, development, and productivity (Bray *et al.* 2000). Each abiotic factor's number or intensity determines how it affects the plant. The plant needs a specific amount of each abiotic environmental element for optimum growth.

The earth's climate is changing quickly, according to the most recent scientific research. Due to global warming, the already poor situation will soon get significantly worse as desertification continues to rise and the annual loss of arable land might treble by the end of the century. (Evans 2005; Vinocur and Altman 2005). The main abiotic stresses—high salt, heat, cold, and drought—have a 70% negative impact on the survival, biomass production, and yields of key food crops. (Vorasoot et al. 2003).

In the contemporary global landscape, plant stress detection is regarded as one of the most important topics for improving crop productivity. With this wide-ranging view, there are numerous options for technology. Qualitative techniques like fluorescence, thermography, and VIS/NIR reflectance offer a non-disruptive picture of how stresses are affecting plants, even over vast regions. The effects of stress can be seen at different spatial scales, ranging from the DNA level (nanometers) to the cell (micrometres), the entire plant (millimeters to meters), and the field (kilometers). Only qualitative methods can be used to greater scales. (Galieni *et al.*, 2021).

As one of the large data sources, remote sensing uses platforms from satellites, manned and unmanned aircraft, and ground-based structures to provide earth-observation data and analytical findings regularly. The advancement of satellite remote sensing technology in particular has allowed for the availability of vast amounts of remotely sensed data for study and other uses. (Liu 2015; Chi et al. 2016).

Currently, there are over a thousand operational satellites orbiting the planet, many of which are used for remote sensing. Typically, these satellites' sensors continuously take pictures of the earth's surface at various temporal and spatial resolutions. (Rosenqvist et al. 2003; Anonymous 2015).

Remote Sensing:

Remote sensing can be defined as learning something about an object without touching it. The field of remote sensing can be divided into two general categories: analog remote sensing and digital remote sensing. Analog remote sensing included use of film to record the electromagnetic energy. Digital remote sensing included use of some type of sensor to convert the electromagnetic energy into numbers that can be recorded as bits and bytes on a computer and then displayed on a monitor. Modern tiny satellites, which revolutionized the satellite paradigm in the late 1980s, created new opportunities for space applications.

From 1957 to 1969, the first microsatellites were launched. A total of 238 mini-satellites and 249 micro-satellites were launched between 1980 and 1999 from various countries across the world, such as China, India, Germany, Japan, Korea, Saudi Arabia, China, Algeria, and Malaysia. In 1999, a special issue on tiny satellite engineering was released. (Swinerd 1999). The International Workshop on Earth Observation Small Satellites for Remote Sensing Applications took place in Kuala Lumpur, Malaysia from November 13–16, 2007. Based on Dr. Kramer's presentation at that Workshop (Kramer 2007), Kramer and Cracknell (2008) have produced an overview of tiny satellites in remote sensing.

Steps involved in remote sensing included:

Digital Image Analysis: It is the process by which the selected imagery is converted/processed into information in the form of a thematic map. Digital image analysis is performed through a series of steps. These steps include (1) image acquisition/selection, (2) pre-processing including image enhancement, (3) classification, (4) post-processing, and (5) accuracy assessment.

Image Acquisition/Selection: The application of the study and the budget come first when choosing or purchasing suitable remotely sensed imagery.

Pre-processing: Pre-processing is defined as any technique performed on the image before the classification.

Classification: Only spectral information (tone/color) used to classify digital data.

Post-processing: Post-processing can be defined as those techniques applied to the imagery after it has been through the classification process.

Change Detection: Images can be used to simply identify binary "change versus no-change" or "from-to change"

Accuracy Assessment: Accuracy assessment is a vital step in any digital remote sensing project. (Congalton, R. G. 2010).

Remote Sensing in Precision Agriculture:

Since its establishment in the 1980s, precision agriculture has transformed agricultural operations by integrating remote sensing, geographic information systems (GIS), and global positioning systems (GPS). This approach was based on agricultural mechanization. Precision agriculture has changed over the last three decades from strategic monitoring based on satellite imaging for local decision-making to tactical monitoring and control guided by data from low-altitude remotely sensed data for site-specific treatment at the field level (Zhang et al. 2002).

Broad-band multispectral or narrow-band hyperspectral data capture, both imaging and non-imaging, is the primary use of sensors. To accommodate sensors aboard manned and unmanned aircraft, space-borne platforms are utilized, whereas ground-based platforms are best suited for laboratory and field sensors that need to be deployed quickly. Agricultural remote sensing is an extremely specialized subject that produces extremely complicated and large volumes of pictures and spectral data to inform agricultural development decisions. To enhance decision-making regarding fertilization, irrigation, and pest management for crop production, remote sensing is used in agricultural areas to monitor crop stress and soil parameters. Early plant stress detection offers the chance to make early management changes to enhance crop output and quality. (Kim et al., 2010).

Remote Sensing Qualitative Methods for Abiotic Stress Detection:

A healthy leaf emits fluorescence when stimulated by UV radiation. The wavelengths of radiation are blue (440 nm), green (520 nm), red (690 nm), and far-red (740 nm). The electromagnetic signal that is reflected by the plant leaves during reflectance-based remote sensing is used to record the data. Changes in leaf components are the parameters tracked in reflectance-based remote sensing for plant stress. (Chaerle *et al.* 2002).

Firstly, plants and electromagnetic radiation interact, which is the basis of most of the processes involved. Plants can undergo a wide range of intricate physiological and biochemical reactions to stressful situations, including changes in stomatal conductance, pigment content, and biochemistry. In the previous few decades, agricultural sciences primarily relied on reflectance (in the thermal (in the thermal infrared, TIR, 7.0–20.0 µm region), fluorescence (at 0.68 and 0.74 µm wavelengths), and near-infrared (NIR, 0.7–1.3 µm and short wave-infrared, SWIR, 1.3–2.5 µm) sensors. Additionally, sensors can be categorized according to how they are used in (i) non-imaging techniques (such as VIS, multispectral and hyperspectral imaging, thermal imaging, fluorescence imaging, and x-ray imaging) and (ii) imaging techniques (such as VIS, multispectral and hyperspectral imaging, and fluorescence imaging). Since non-imaging sensors do not give spatial information, they are generally better suited for measurements made at lab or leaf scales. The great resolution of the sensors that are currently on the market aids in identifying potential relationships between minute processes occurring at the tissue level and plant electromagnetic patterns after exposure to stress. (Thomas et al., 2017, 2018). The spatial resolution is a crucial component in gathering data on plant responses to stress

at the canopy or landscape levels. For instance, proximal hyperspectral imaging is more effective than hyperspectral remote sensing in the field of characterizing a particular disease. (Kuska and Mahlein, 2018). Every sensing approach has a unique level of efficacy in identifying and detecting stress, which varies depending on the level of technical advancement attained and the inherent features of the technology being used. It depends on (i) the kind of stressful conditions and (ii) its magnitude early identification of stressful conditions is important In the event of water stress, for instance, temperature-based indices offer a suitable pre-visual identification of plant reactions. (Gerhards et al., 2019).

Secondly, Plant genotype is connected to spectrum responses to stress exposure within the same sensing vegetation technology and stressful circumstances. To produce indicators or parameters for certain demands, this element could require a thorough investigation of particular stress-genotype combinations together with an understanding of the physiological and biochemical mechanisms that lead to changes in the spectrum feature. Thirdly, data collection procedures should take into account the plant canopy and leaf structural architecture, as well as the measuring environment. Enhancements are required for (i) pre-processing data, (ii) integrating calibrating systems on automated systems, and (iii) utilizing multiple sensors. platforms with 3-D shape sensors installed as well. (Mishra et al., 2020).

Fourthly, the identification of specific stressors can be challenging, particularly in open-field conditions where a multi-stress scenario can occur, because certain plant responses which may be detectable for stress diagnosis may be shared among various stresses (e.g., drought, salinity, temperatures, mineral toxicity, or pathogen infection). Single-sensing techniques have the potential to identify individual stress signals with high specificity in experimental settings. However, a comprehensive and integrated approach is necessary to identify potential multiple causes in agricultural applications (Jones and Schofield, 2008). The aforementioned factors provide a fresh foundation for the development of vegetation sensing for stress detection by utilizing existing methods and introducing and enhancing cutting-edge imaging techniques that are useful for the agricultural industry. (Mishra et al., 2017; Khan et al., 2018; Gerhards et al., 2019; Gorbe and Calatayud, 2012; Murchie and Lawson, 2013).

Fluorescence Spectroscopy:

A specific wavelength of light is absorbed by fluorescent molecules, which then change their electronic shell and eventually return to their original state while releasing some of the absorbed energy as an electromagnetic wave. Every molecule has unique wavelengths for absorption and emission. For example, chlorophyll fluorescence (ChlF) has two peaks in the far-red (735 nm) and red (680 nm) wavelength ranges of its natural emission, which fall between 650 and 800 nm. Variations in the chlorophyll content of leaves can be detected by variations in the shape of the fluorescence spectra and the ratio of the two maxima emission peaks (F685/F735). (Buschmann, 2007; Pandey et al., 2015). Following plant exposure to both biotic and abiotic stressful circumstances, ChlF and ChlF parameters are commonly used to quickly assess any mutation of Photosystem II.

Vis/NIR Spectroscopy:

With both active and passive sensors, leaf and/or canopy reflectance has been extensively studied under a variety of biotic and abiotic stressful situations. While the latter rely on sunlight as their light source, the former are equipped with light-emitting components. Since reflectance in the VIS, NIR, and SWIR is predominantly controlled by photosynthetic pigments, cell structure, and water content, respectively, the principal applications in plant health detection are based on spectral wavelengths ranging from 400 to 2,500 nm. In reality, when plants develop in poor settings, these features can undergo significant alterations. (Mishra et al., 2017).

Reflectance spectroscopy is generally utilized to sense a variety of stressful situations. The assessment of crops' nitrogen status is a topic covered in some of the more current work on this subject. (Stellacci et al., 2016), the effects of salinity on crop growth and yield (Boshkovski et al., 2020); the plant changes brought on by drought (Stagnari et al., 2014; Maimaitiyiming et al., 2017; Sylvain and Cecile, 2018); the accumulation of particular secondary metabolites in plant tissue (Couture et al., 2016); and the phenotyping of plants (Garriga et al., 2017; Ge et al., 2019), the macro- and micro-nutrient deficiencies (Galieni et al., 2015). These days, the majority of reflectance spectroscopy technologies are based on hyperspectral sensors, which allow for massive data collection by allowing images to be acquired in some tiny (<10 nm) and contiguous spectral bands.

Thermal Imaging:

Because of the strong correlations between foliar surface temperature (Tleaf) and leaf gas exchange (CO_2 and H_2O fluxes controlled by stomatal closure or aperture) or stomatal conductance (gs), it can be effectively used in the identification of stressed circumstances (Gutirrez et al., 2018). Well-known and extensively studied subjects include the physical rules governing body emission in the TIR region and the atmospheric and environmental factors influencing the Tleaf-gs connection. (Valu et al., 2013; Vialet-Chabrand and Lawson, 2019; Jones and Schofield, 2008). Its primary uses are in agriculture and phenotyping, specifically in the establishment of irrigation schedules and sensing for crop water stress detection (Gutirrez et al., 2018).

Fluorescence Imaging

The emergence of novel technologies has made it possible to construct an image by simultaneously accumulating a large number of punctual fluorescence spectroscopic signals, each of which is encoded with a color-value connection. Typically, the system consists of a charge-coupled device (CCD) camera and a UV light

source to excite the fluorescent molecules. (Sankaran et al., 2010). Moreover, fluorescence imaging is a helpful tool for examining stressful situations caused by nutrient deficiencies (Wang et al., 2018c), extreme temperatures (Dong et al., 2019; Lu and Lu, 2020), drought and/or salinity (Yao et al., 2018; Sun et al., 2019).

Multi- and Hyperspectral Imaging and Thermal Hyperspectral Remote Sensing for Stress Characterization:

The classification of spectral sensors is based on the resolution of the measure (i.e., the density of wavebands in the measure). Multi- and hyperspectral sensors can load data from a continuous and wider VIS/NIR band, usually between 400 and 1,000 nm, with the most sophisticated systems reaching the 350–2,500 nm band (Stellacci et al., 2016; Maes and Steppe, 2019). The spectral resolution of multispectral sensors is approximately 50 nm, whereas hyperspectral sensors have a resolution of 1 to 10 nm (Mahlein, 2016; Stellacci et al., 2016). Nevertheless, because they are more widely available and less expensive, multi-spectral sensors are currently beneficial only in agricultural applications.

Because the spectrum information is combined with the spatial and temporal dimensions in the image-based VIS/NIR technique, it is possible to assess the occurrence of stressful situations even at the landscape scale (Zhang et al., 2019a). Real-time monitoring of the water state, biomass and yield, nutrient status, disease, and pests is facilitated by spaceborne, aerial, and ground-based systems (Xue and Su, 2017; Maes and Steppe, 2019; Zhang et al., 2019a; Caballero et al., 2020).

Until recently vegetation spectra in the mid-and thermal-infrared region (MIR: 2.5–6.0 µm and TIR: 8.0–14.0 µm) have been considered featureless. Most spectral features of plant leaves in the TIR domain have been overlooked due to lack of equipment, poor signal-to-noise ratio and the complex nature of the spectral characteristics of vegetation (Ribeiro da Luz and Crowley 2007). However, recent advances in TIR application led to the discovery that the spectral signatures of fresh plants are dominated by epidermal materials of leaves (i.e. cell wall and cuticle) (Salisbury, 1986). The reflectance spectra of green leaves taken by high-resolution sensors in the TIR region revealed a broad range of distinctive spectral features (Salisbury 1986; Salisbury and Milton 1988). The spectral response of fresh and completely dried leaves measured in the mid-to thermal-infrared region revealed significant variation in the mid-infrared spectral response, emphasizing the potential use of mid-infrared for leaf water content quantification (Gerber et al. 2011). Remotely sensed data using TIR radiation has been successfully used to detect water-deficit stress even before visual symptoms of the same appeared (Möller et al. 2006). Fresh leaves showed the lowest MIR and TIR reflectance, and with the decrease in leaf water content, reflectance increased. In the MIR, the variation in reflectance was more prominent between 2.5 and 3.0 µm (maximum reflectance of about 30%) and 3.5–5.8 µm (maximum reflectance of about 16%). The absorption characteristics at 3.05 µm and 4.65 µm are related to the leaf water content (Ribeiro da Luz 2006; Fabre et al. 2011). Cheng *et al.* (2011) reported better retrieval of leaf water content retrieval from the MIR to TIR spectra (R2 ¼ 0.88) than that obtained from VNIR to SWIR spectra (R2 ¼ 0.77). The correlation between leaf water content and spectral response over the entire MIR region was reported to be negative (Ullah *et al.* 2013).

Abiotic Stress Monitoring:

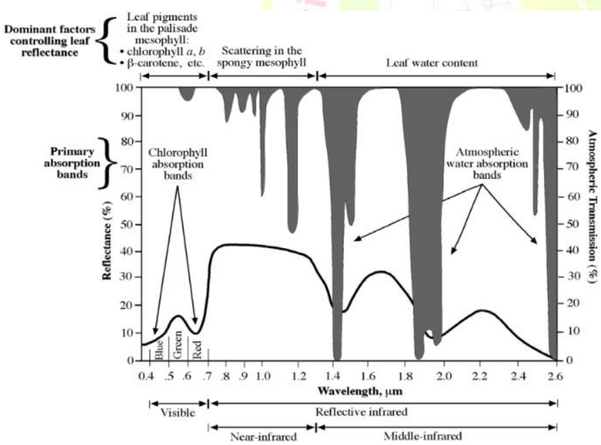
Water-Deficit Stress Monitoring:

A variety of approaches with differing degrees of precision and application have been tried, such as assessing the water content of soil or plants, the concentrations of pigments or nitrogen, dry matter, and the leaf area index (LAI) (Carter 1993; Peñuelas *et al.* 1994). Scientists concluded sensors can accurately detect the water-deficit stress that is being applied. (Sinclair and Ludlow 1985). Leaf water content can effectively indicate the health and vigour of a plant along with its photosynthetic efficiency (Harry, 2006). The selection of suitable genotypes in breeding for water-deficit stress tolerance provides advanced prediction for monitoring the physiological status of any vegetation (Harry, 2006). Apart from these, precise estimates of plant water content can be used for drought risk assessment (Bauer et al. 1986). Plant water deficit stress or drought stress is one of the major limiting factors which affects yield and is usually detected only after it becomes visually apparent. So, an accurate estimation of plant water status or relative water content (RWC) is a major factor in the decision-making process regarding general land use, crop irrigation and drought assessment (Peñuelas *et al*. 1997). RWC can be defined as the ratio of the volume of water present in a leaf to the water volume of the leaf at fully turgid conditions (Hunt and Rock 1989). Assessment of water-deficit stress can be done by taking plant canopy or leaf level reflectance measurements, as they show change in response to changing RWC of the plant (Gutierrez *et al*. 2010). Different species may exhibit different symptoms of water-deficit stress; however, one of the common effects of water-deficit stress across all the species is the change in plant's spectral (Peñuelas *et al*. 1993). The water absorption bands can be of good use in the estimation of the plant's RWC.

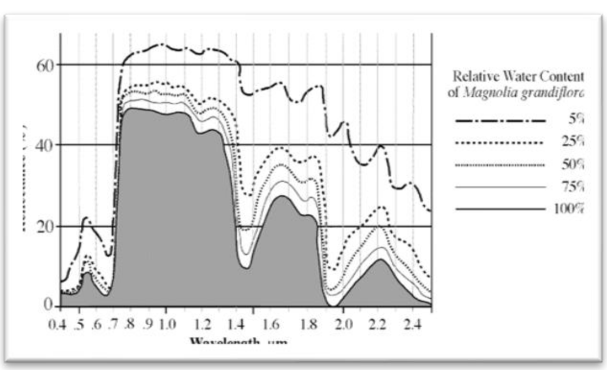
The reflectance of plant leaf or canopy particularly beyond visible spectral range is mostly governed by leaf water content. Therefore, it can indirectly be used for non-destructive in-situ evaluation of plant water status. Canopy reflectance obtained from hyperspectral sensors besides offering quick and easy measurements enables the estimation of some additional parameters through a series of different spectral indices (e.g., chlorophyll content, LAI, intercepted radiation and photosynthetic capacity) (Araus *et al.* 2001). Of its versatile nature, canopy reflectance is a very useful tool for high-throughput phenotyping (Montes *et al*. 2007; Chapman 2008).

Effect of Stress on Plant's Spectral Signature:

Recognizing an object in isolation from its surroundings is remote sensing's main goal. It is referred to as spectrum reflectance if this is accomplished through reflectance measurements. In the wavelength range of 400-2700 nm, the spectral reflectance of the vegetation varies with wavelength and can be split into three primary wide zones. (Gates *et al.* 1965). The response is dominated by the pigmentation of leaves, specifically chlorophyll, carotene, and xanthophylls, in the visible spectrum (400–700 nm). Low reflectance and high absorbance, particularly at blue and red wavelengths, define this region. (Gausman 1974). The NIR region has two weak water absorption features at wavelengths 950–970 and 1150–1260, respectively (Sims and Gamon 2002). There are three main water absorption bands are present at 1400 nm, 1900 nm, and 2700 nm. The response in the shortwave infrared (SWIR) spectrum (1300-2700 nm) is primarily influenced by the water content of the same leaves. The visible-near-infrared (VNIR) and SWIR spectra have been extensively explored for determining leaf water content (Ceccato *et al*. 2002; Cheng *et al.* 2011). Water molecules present in leaves weakly absorb radiation in the NIR (720–1000 nm) region and strongly absorb in the SWIR (1400–1900 nm) region (Datt 1999).



Typical spectral reflectance pattern of leaf. Source: Jensen (2009).



Source: Jensen (2009)

than the NIR region for measuring leaf water content (Datt 1999). Numerous investigations found a significant relationship between leaf water content and reflectance and derivative spectra between 1400 and 1900 nm. (Ceccato *et al*. 2001, 2002; Champagne *et al*. 2003). If the chlorophyll content decreases as a result of biotic and abiotic stressors, the reflectance in the visible region increases. The reflectance in the NIR region of the electromagnetic spectrum will be reduced if disease or pests harm the leaves.

Spectral Indices for Characterizing Stress:

The vegetation indices (VIs), which highlight a certain aspect of the vegetation, are combinations of spectral responses in several wavebands. (Wiegand *et al*. 1991). Composite indices are more capable of detecting changes in a plant's biophysical and biochemical characteristics brought on by biotic and abiotic stressors than individual spectral bands (Asrar *et al.* 1984). The indexes also attempt to minimize the complexity of the multispectral/hyperspectral data and standardize the representation of crop spectral responses, which aids in comparing crops across regions. (Malingreau 1989). The NDWI was created to evaluate the condition of the water using airborne hyperspectral imaging with a considerably greater spatial resolution (Gao, 1996). NDWI is a reasonably accurate indicator of vegetation water content because it is less subject to atmospheric scattering caused by water vapours. It can also function using the 1640 nm and 2130 nm water absorption bands (Chen *et al.* 2005). According to Zarco-Tejada *et al.* (2003), the simple ratio water index (SRWI; R860/R1240) can be used to estimate plant water content concerning LAI, equivalent water thickness (EWT), and leaf biomass. The difference between the reflectance spectra of two spectral bands serves as the basis for the VIs, also known as simple ratio and normalized difference indices (Rouse *et al*. 1974). Spectral indices, such as WI or NDWI, use straightforward ratios of the reflectance at a wavelength within the water absorption bands and another wavelength from outside the water absorption bands, ideally used as a control, to identify changes in plant water content. (Sims and Gamon 2002). Indicators such as the red edge inflexion point (REIP) and the normalized differential vegetation index (NDVI) make use of wavelengths that are impacted by changes in the cellular makeup or pigment content of leaves. (Horler *et al.* 1983). The majority of the indices currently in use, such NDWI and WI, employ wavelengths in the near-infrared (NIR, 700-1300 nm) range. Even though numerous research has demonstrated the existence of meaningful connections between these indices and plant water status. (Peñuelas *et al*. 1997; Serrano et al. 2002; Pu *et al.* 2003; Asner and Martin 2008). It has been suggested that wavelengths in the SWIR rather than the NIR could more accurately depict changes in plant water status. (Tucker 1980). The SWIR wavebands located in the range of 1500–1750 nm have been identified as

useful for monitoring plant water content (Ceccato *et al.* 2002; Chen et al. 2005; Eitel *et al.* 2006).

Characterization of Stresses through Plant Pigment Assessment:

Under stressful conditions, the amount of leaf chlorophyll drops, which reduces the amount of light that is absorbed overall in the visible spectrum (Zarco-Tejada *et al.,* 2001). The usual spectral reflectance pattern of plants is altered as a result of these alterations, which results in a decrease in green reflection and an increase in red and blue reflections. The location and form of the spectral red edge are significant indications of plant water status when chlorophyll content is utilized as a measure of plant water-deficit stress (Horler *et al*. 1983). The (R850 R710)/(R850 R680) index was proposed by Datt (1999) utilizing the leaf reflectance of 21 Eucalyptus species. Sims and Gamon (2002) created some indices using a sizable database that included over 400 leaves and a variety of functional categories, leaf structures, and developmental stages. They then compared these indices to ones that were already in use. They discovered that when it came to connection with chlorophyll concentration, indices mSR705 and mND705 were far superior to others.

According to Gitelson and Merzlyak (1994), chlorophyll-a absorbs light at a wavelength of 670 nm with the highest sensitivity of reflectance. They concluded that the wavebands with the greatest sensitivity to chlorophyll-a levels were 550–560 nm and 700–710 nm. For pigment estimation, Blackburn (1999) identified the optimal individual wavebands, e.g., 680, 635 and 470 nm for chlorophyll-a, chlorophyll-b and carotenoids, respectively. Concentrations of both chlorophyll-a and chlorophyll-b in bracken (Pteridium aquilinum) were found to be best correlated with 676 nm (Blackburn 1998). Chlorophyll-a displayed the strongest connection with 680 nm wavelength at senescence in the same study. Gitelson and Merzlyak (1997) obtained an inaccuracy of less than 4.2 g cm^2 while predicting leaf chemicals using an algorithm created from leaf optics and verified over nine species with a range of 0.27 to 62.9 g cm^2 of chlorophyll.

Remote Sensing of Water Stress:

Remote sensing offers a quick, affordable, non-destructive, and spatio-temporal measure of a variety of physiological, biochemical, and structural crop parameters at various scales (ground, airborne, and satellite). Plants may experience permanent damage before observable signs of water stress arise. (Mahajan et al. 2005, Yardoanov et al. 2003, Jones et al. 2008). So, a pre-symptomatic or pre-visual identification of physiological changes in plants can essentially help to prevent serious crop damage. (Chaerle et al. 2000). With its continuous spectrum data, hyperspectral photography can provide more light on the connection between spectral traits and related plant states. (Pinter et al. 2003).

Challenges and Future Perspectives:

For the assessment and tracking of stress, imaging technologies have emerged as a crucial tool that helps physiologists, breeders, and agronomists with both in-field and lab research. Stress can be seen on many different length scales, from the tiny cellular level to the macroscopic level in plants and fields. In agricultural applications, whole-field sensing is inherently appealing. Qualitative remote sensing technologies and techniques have the tremendous advantage of being able to detect quickly and provide indications on a wide range of scales, from the microscopic to the landscape. Furthermore, the use of robotic platforms makes it possible to continuously monitor vegetation.

Owing to its great versatility, the most significant limitations, however, are associated with the accurate definition of protocols for measurements, processing, and pre-processing of data collected; these steps should account for the variability of environmental conditions that arise during measurements, as they have the potential to impair the accuracy and dependability of the results obtained. Improved decision-making about the application of water and other nutrients is possible for farmers through the combination of remote sensing and plant physiological investigations (Jones et al., 2004).

CONCLUSION

In summary, this review emphasizes an overview of the crucial role that remote sensing plays in the detection and management of abiotic stress in plants. Remote sensing is a significant quick, and affordable method for monitoring and managing abiotic stress in plants, ultimately promoting sustainable agriculture and food security. Remote sensing helps to establish sustainable agricultural practices and mitigate the problems associated with food security in a constantly changing climate by expanding our understanding of how plants react to environmental stressors. We covered the main abiotic stressors in this study, including salinity, drought, and nutrient deficiencies, as well as how multispectral and hyperspectral data can be used to detect stress-induced responses, such as changes in leaf reflectance, chlorophyll content, and hydration status. To make it easier to identify areas of stressed plants, we investigated several indices and algorithms used to extract useful information from the collected picture. We also investigate accurate identification depending on understanding how abiotic stressors affect plants' spectral signatures.

Remote sensing can be used to record and analyse changes in reflectance patterns, chlorophyll content, and water status as a result of stressors such as drought, salt, and nutrient deficiency. The ability to recognize these spectrum variations is a crucial component of stress detection. Physiological aspects are also included in it. Researchers and practitioners can better understand how plants respond to stress by fusing spectral data with physiological models. The assessment of the health of the plant, the degree of the stress, and the creation of specialized management techniques are all made possible by this method.

In conclusion, the interaction between remote sensing technology and physiological aspects of plant response to abiotic stresses holds great promise for improving our capacity to monitor and manage stressors, resulting in more sustainable agriculture, ecological management, and informed decision-making in a changing world.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Anderson, M.; Zolin, C.; Sentelhas, P.; Hain, C.; Semmens, K.; Tugrul Yilmaz, M.; Gao, F.; Otkin, J.; Tetrault, R. 2016. The Evaporative Stress Index as an indicator of agricultural drought in Brazil: An assessment based on crop yield impacts. *Remote Sens. Environ*., **174**, 82–99.

Anonymous. 2015. The 10 countries are most active in space. [2017- 10-25]. http://www.aerospace-technology.com/features/ feature the-10-countries-most-active-in-space-4744018/

Asrar GQ, Fuchs M, Kanemasu ET, Hatfield JL 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat 1. *Agron J* **76**:300–306

Bauer ME, Daughtry CST, Biehl LL et al 1986. Field spectroscopy of crops. IEEE Trans Geosci Remote Sens GE-24:65–75. https://doi.org/10.1109/TGRS.1986.289589

Blackburn GA 1998. Spectral indices for estimating photosynthetic pigment concentrations: a test using senescent tree leaves. *Int J Remote Sens* **19**:657–675. https://doi.org/10.1080/ 014311698215919

Blackburn GA 1999. Relationships between spectral reflectance and pigment concentrations in stacks of deciduous broadleaves. *Remote Sens Environ* **70**:224–237

Borel, C. 1997. Iterative Retrieval of Surface Emissivity and Temperature for a Hyperspectral Sensor. In Proceedings of the Proceedings for the First JPL Workshop on Remote Sensing of Land Surface Emissivity, Pasadena, CA, USA, 6–8 May 1997.

Borel, C.C. 2003. ARTEMISS—An Algorithm to Retrieve Temperature and Emissivity from Hyper-Spectral Thermal Image Data. In Proceedings of the 28th Annual GOMACTech Conference, Hyperspectral Imaging Session, Tampa, FL, USA, 31 March–3 April 2003; pp. 3–6.

Boshkovski, B., Tzerakis, C., Doupis, G., Zapolska, A., Kalaitzidis, C., and Koubouris, G. 2020. Relationships of spectral reflectance with plant tissue new avenues towards tailoring food crop quality. Agronomy 8:138. doi: 10.3390/agronomy8080138

Bray EA, Bailey-Serres J, Weretilnyk E 2000) Responses to abiotic stresses. In: Buchanan BB, Gruissem W, Jones RL (eds) Biochemistry and molecular biology of plants. American Society of Plant Physiologists, Rockville, pp 1158–1203

Buschmann, C. 2007. Variability and application of the chlorophyll fluorescence emission ratio red/far-red of leaves. *Photosynth. Res*. **92**, 261–271. doi: 10.1007/s11120-007-9187-8

Caballero, D., Calvini, R., and Amigo, J. M. 2020. "Chapter 3.3: Hyperspectral imaging in crop fields: precision agriculture," in Hyperspectral Imaging Data Handling in Science and Technology, ed J. M. Amigo (Amsterdam: Elsevier), 453–473. doi: 10.1016/B978-0-444-63977-6.00018-3

Ceccato P, Flasse S, Grégoire J-M 2002. Designing a spectral index to estimate vegetation water content from remote sensing data. Remote Sens Environ 82:198–207. https://doi.org/10.1016/ S0034-4257(02)00036-6

Ceccato P, Flasse S, Tarantola S et al 2001. Detecting vegetation leaf water content using reflectance in the optical domain. *Remote Sens Environ* 77:22–33. https://doi.org/10.1016/ S0034-4257(01)00191-2

Chaerle L, De Boever F, Van Der Straeten D 2002. Infrared detection of early biotic and wound stress in plants. *Thermol Int* **12**:100–106

Champagne CM, Staenz K, Bannari A et al 2003. Validation of a hyperspectral curve-fitting model for the estimation of plant water content of agricultural canopies. *Remote Sens Environ* **87**:148–160. https://doi.org/10.1016/S0034-4257(03)00137-8

Chapman SC 2008. Use of crop models to understand genotype by environment interactions for drought in real-world and simulated plant breeding trials. *Euphytica* **161**:195–208

Chen X, Vierling L, Deering D 2005. A simple and effective radiometric correction method to improve landscape change detection across sensors and across time. *Remote Sens Environ* **98**:63–79

Cheng T, Rivard B, Sánchez-Azofeifa A 2011. Spectroscopic determination of leaf water content using continuous wavelet analysis. *Remote Sens Environ* **115**:659–670. https://doi.org/10.1016/ j.rse.2010.11.001

Cheng W, Yagi K et al 2005. Influence of elevated concentrations of atmospheric CO2 on CH4 and CO2 entrapped in rice-paddy soil. *Chem Geol* **218**:15–24

Chi M, Plaza A, Benediktsson J A, Sun Z, Shen J, Zhu Y. 2016. Big data for remote sensing: Challenges and opportunities. Proceedings of the IEEE, **104**, 2207–2219.

Congalton, R. G. 2010. Remote sensing: an overview. *GIScience & Remote Sensing*, **47**(4), 443-459.

Couture, J. J., Singh, A., Nason, K. F. R., Serbin, S. P., Lindroth, R. L., and Townsend, P. A. 2016. Spectroscopic determination of ecologically relevant plant secondary metabolites. *Methods Ecol. Evol*. **7**: 1402–1412. doi: 10.1111/2041-210X.12596

Datt B .1999. Remote sensing of water content in eucalyptus leaves. *Aust J Bot* **47**:909. https://doi.org/10.1071/BT98042

Dong, Z., Men, Y., Li, Z., Zou, Q., and Ji, J. 2019. Chlorophyll fluorescence imaging as a tool for analyzing the effects of chilling injury on tomato seedlings. Sci. Hortic**.** **246**, 490–497. doi: 10.1016/j.scienta.2018.11.019

Eitel JUH, Gessler PE, Smith AMS, Robberecht R 2006. Suitability of existing and novel spectral indices to remotely detect water stress in Populus spp. *For Ecol Manag* **229**: 170–182.
https:// doi.org/10.1016/j.foreco.2006.03.027

Evans LT 2005. Is crop improvement still needed? *J Crop Improv* 14:1–7

Fabre S, Lesaignoux A, Olioso A, Briottet X 2011. Influence of water content on spectral reflectance of leaves in the 3–15- μm domain. *IEEE Geosci Remote Sens Lett* **8**:143–147. https://doi.org/10.1109/LGRS.2010.2053518

Gago, J.; Douthe, C.; Coopman, R.E.; Gallego, P.P.; Ribas-Carbo, M.; Flexas, J.; Escalona, J.; Medrano, H. 2015. UAVs challenge to assess water stress for sustainable agriculture. Agric. Water Manag. **153**, 9–19.

Galieni, A., D'Ascenzo, N., Stagnari, F., Pagnani, G., Xie, Q., & Pisante, M. 2021. Past and future of plant stress detection: an overview from remote sensing to positron emission tomography. *Frontiers in Plant Science*, **11,** 609155.

Galieni, A., Mattia, C. D., Gregorio, M. D., Speca, S., Mastrocola, D., and Pisante, M. 2015. Effects of nutrient deficiency and abiotic environmental stresses on yield, phenolic compounds and antiradical activity in lettuce (*Lactuca sativa* L.). *Sci. Hortic*. 187, 93–101. doi: 10.1016/j.scienta.2015.02.036

Gamon, J.; Peñuelas, J.; Field, C. 1992. A narrow-waveband spectral index that tracks diurnal changes in photosynthetic efficiency. *Remote Sens. Environ*. **41**: 35–44.

Gao B-C 1996. NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sens Environ* **58**:257–266. https://doi.org/10.1016/S0034-4257(96)00067-3

Garriga, M., Romero-Bravo, S., Estrada, F., Escobar, A., Matus, I. A., and del Pozo, A. 2017. Assessing wheat traits by spectral reflectance: do we really need to focus on predicted trait-values or directly identify the elite genotypes group? *Front. Plant Sci*. **8**:280. doi: 10.3389/fpls.2017.00280

Gausman HW 1974. Leaf reflectance of near-infrared. *Photogramm Eng* **40**:183–191

Ge, Y., Atefi, A., Zhang, H., Miao, C., Ramamurthy, R. K., and Sigmon, B. 2019. High-throughput analysis of leaf physiological and chemical traits with VISNIR-SWIR spectroscopy: a case study with a maize diversity panel. *Plant Methods* **15**, 1–12. doi: 10.1186/s13007-019-0450-8

Gerber F, Marion R, Olioso A et al 2011. Modeling directional–hemispherical reflectance and transmittance of fresh and dry leaves from 0.4μm to 5.7μm with the PROSPECT-VISIR model. *Remote Sens Environ* **115**:404–414. https://doi.org/10.1016/j.rse.2010.09.011

Gerhards, M., Schlerf, M., Mallick, K., and Udelhoven, T. 2019. Challenges and future perspectives of multi-/hyperspectral thermal infrared remote sensing for crop water-stress detection: a review. Remote Sens. 11:1240. doi: 10.3390/rs11101240

Gerhards, M.; Schlerf, M.; Rascher, U.; Udelhoven, T.; Juszczak, R.; Alberti, G.; Miglietta, F.; Inoue, Y. 2018. Analysis of Airborne Optical and Thermal Imagery for Detection of Water Stress Symptoms. *Remote Sens*. **10**, 23.

Gitelson AA, Merzlyak MN 1997. Remote estimation of chlorophyll content in higher plant leaves. Int J Remote Sens 18:2691–2697

Gorbe, E., and Calatayud, A. 2012. Applications of chlorophyll fluorescence imaging technique in horticultural research: a review. *Sci. Hortic*. **138**, 24–35. doi: 10.1016/j.scienta.2012.02.002

Grant, O.M.; Chaves, M.M.; Jones, H.G. 2006. Optimizing thermal imaging as a technique for detecting stomatal closure induced by drought stress under greenhouse conditions. Physiol. Plant. 127, 507–518.

Gutierrez M, Reynolds MP, Klatt AR 2010. Association of water spectral indices with plant and soil water relations in contrasting wheat genotypes. *J Exp Bot* **61**:3291–3303

Gutiérrez, S., Diago, M. P., Fernández-Novales, J., and Tardaguila, J. 2018. Vineyard water status assessment using on-the-go thermal imaging and machine learning. PLoS ONE 13:e0192037. doi: 10.1371/journal.pone.0192037

Harry V 2006) Principles of soil and plant water relations. *Geoderma* 133:478

Hecker, C.; Hook, S.; van der Meijde, M.; Bakker, W.; van der Werff, H.; Wilbrink, H.; van Ruitenbeek, F.; de Smeth, B.; van der Meer, F. 2011. Thermal infrared spectrometer for Earth science remote sensing applications-instrument modifications and measurement procedures. Sensors 11, 10981–10999.

Hecker, C.A.; Smith, T.E.L.; da Luz, B.R.; Wooster, M.J. Thermal Infrared Spectroscopy in the Laboratory and Field in Support of Land Surface Remote Sensing. In Thermal Infrared Remote

Sensing; Kuenzer, C., Dech, S., Eds.; Springer: Dordrecht, The Netherlands; pp. 43–67.

Horler DNH, Docray M, Barber J .1983. The red edge of plant leaf reflectance. *Int J Remote Sens* **4**:273–288. https://doi.org/10.1080/01431168308948546

Idso, S.B.; Jackson, R.D.; Pinter, P.J.; Reginato, R.J.; Hatfield, J.L. 1981. Normalizing the stress-degree-day parameter for environmental variability. *Agric. Meteorol*. **24**: 45–55.

Jensen JR 2009. Remote sensing of the environment: an earth resource perspective 2/e. Pearson Education India, Chennai

Jones, C. L., P. R. Weckler, N. O. Maness, M. L. Stone, and R. Jayasekara, 2004. Estimating water stress in plants using hyperspectral sensing. 2004 ASAE/CSAE Annual International Meeting. Ottawa, Ontario, Canada.

Jones, H., and Schofield, P. 2008. Thermal and other remote sensing of plant stress. *Gen. Appl. Plant Physiol*. **34**:19–32.

Khan, M. J., Khan, H. S., Yousaf, A., Khurshid, K., and Abbas, A. 2018. Modern trends in hyperspectral image analysis: a review. *IEEE Access* **6**, 14118–14129. doi: 10.1109/ACCESS.2018.2812999

Kim, Y., D. M. Glenn, J. Park, H. K. Ngugi, and B. L. Lehman, 2010. Hyperspectral image analysis for plant stress detection. 2010 ASABE Annual International Meeting. Pittsburg, Pennsylvania.

Kramer, H.J. and Cracknell, A.P., 2008. An overview of small satellites in remote sensing. International Journal of Remote Sensing, 29, pp. 4285–4337

Kramer, H.J., 2007. An overview of small satellite in remote sensing. In Proceedings of International Workshop on Earth Observation Small Satellites for Remote Sensing Applications, Kuala Lumpur, Malaysia, 2007 CD, Universiti Teknologi Malaysia, Johor Bahru.

Liu P. 2015. A survey of remote-sensing big data. *Frontiers in Environmental Science*, **3**: 1–6.

Lu, Y., and Lu, R. 2020. Enhancing chlorophyll fluorescence imaging under structured illumination with automatic vignetting correction for detection of chilling injury in cucumbers. Comput. *Electron. Agric*. **168**:105145. doi: 10.1016/j.compag.2019.105145

Maes, W. H., and Steppe, K. 2019. Perspectives for remote sensing with unmanned aerial vehicles in precision agriculture. *Trends Plant Sci*. **24**: 152–164. doi: 10.1016/j.tplants.2018.11.007

Mahlein, A. K. 2016. Plant disease detection by imaging sensors-parallels and specific demands for precision agriculture and plant phenotyping. *Plant Dis*. **100**: 241–251. doi: 10.1094/PDIS-03-15-0340-FE

Maimaitiyiming, M., Ghulam, A., Bozzolo, A., Wilkins, J. L., and Kwasniewski, M. T. 2017. Early detection of plant physiological responses to different levels of water stress using reflectance spectroscopy. *Remote Sens*. **9:**745. doi: 10.3390/rs9070745

Malingreau JP 1989. The vegetation index and the study of vegetation dynamics. In: Toselli F (ed) Applications of remote sensing to agrometeorology. Springer, Dordrecht, pp 285–303

Meerdink, S.; Roberts, D.; Hulley, G.; Gader, P.; Pisek, J.; Adamson, K.; King, J.; Hook, S.J. 2019. Plant species' spectral emissivity and temperature using the hyperspectral thermal emission spectrometer (HyTES) sensor. *Remote Sens. Environ*. **224**: 421–435.

Meroni, M.; Rossini, M.; Guanter, L.; Alonso, L.; Rascher, U.; Colombo, R.; Moreno, J. 2009. Remote sensing of solar-induced chlorophyll fluorescence: Review of methods and applications. *Remote Sens. Environ*. **113**: 2037–2051.

Mishra, P., Asaari, M. S. M., Herrero-Langreo, A., Lohumi, S., Diezma, B., and Scheunders, P. 2017. Close range hyperspectral imaging of plants: a review. *Biosyst. Eng*. **164**: 49–67. doi: 10.1016/j.biosystemseng.2017.09.009

Möller M, Alchanatis V, Cohen Y et al 2006. Use of thermal and visible imagery for estimating crop water status of irrigated grapevine. J Exp Bot 58:827–838

Montes JM, Melchinger AE, Reif JC 2007. Novel throughput platforms in plant genetic studies. *Trends Plant Sci* **12**:433–436

Murchie, E., and Lawson, T. 2013. Chlorophyll fluorescence analysis: a guide to good practice and understanding some new applications. *J. Exp. Bot*. **64**: 3983–3998. doi: 10.1093/jxb/ert208

Pandey, P., Ramegowda, V., and Senthil-Kumar, M. 2015. Shared and unique responses of plants to multiple individual stresses and stress combinations: physiological and molecular mechanisms. *Front. Plant Sci*. **6**:723. doi: 10.3389/fpls.2015.00723

Peñuelas J, Gamon JA, Fredeen AL et al 1994. Reflectance indices associated with physiological changes in nitrogen- and water-limited sunflower leaves. *Remote Sens Environ* **48**:135–146. https://doi.org/10.1016/0034-4257(94)90136-8

Peñuelas J, Gamon JA, Griffin KL, Field CB 1993. Assessing community type, plant biomass, pigment composition, and photosynthetic efficiency of aquatic vegetation from spectral reflectance. *Remote Sens Environ* **46**:110–118. https://doi.org/10.1016/0034-4257(93)90088F

Pinter, P.J., Jr.; Hatfield, J.L.; Schepers, J.S.; Barnes, E.M.; Moran, M.S.; Daughtry, C.S.; Upchurch, D.R. 2003. Remote Sensing for Crop Management. Photogramm. Eng. *Remote Sens*. 69, 647–664.

Rascher, U.; Alonso, L.; Burkart, A.; Cilia, C.; Cogliati, S.; Colombo, R.; Damm, A.; Drusch, M.;

Guanter, L.; Hanus, J.; et al. 2015. Sun-induced fluorescence - a new probe of photosynthesis: First maps from the imaging spectrometer HyPlant. *Glob. Chang. Biol*. **21**: 4673–4684.

Ribeiro da Luz B, Crowley JK 2007. Spectral reflectance and emissivity features of broad leaf plants: prospects for remote sensing in the thermal infrared (8.0–14.0 μm. *Remote Sens Environ* **109**:393–405. https://doi.org/10.1016/j.rse.2007.01.008

Ribeiro da Luz, B. 2006. Attenuated total reflectance spectroscopy of plant leaves: a tool for ecological and botanical studies. *New Phytol*. 172, 305–318.

Rosenqvist A, Milne A., Lucas R, Imhoff M, Dobson C. 2003. A review of remote sensing technology in support of the Kyoto Protocol. *Environmental Science & Policy*, **6**, 441–455.

Rossini, M.; Nedbal, L.; Guanter, L.; Aˇc, A.; Alonso, L.; Burkart, A.; Cogliati, S.; Colombo, R.; Damm, A.; Drusch, M.; et al. 2015. Red and far-red Sun-induced chlorophyll fluorescence as a measure of plant photosynthesis. *Geophys. Res. Lett*. 42, 1632–1639.

Rouse JW, Haas RH, Schell JA et al 1974. Monitoring the vernal advancements and retrogradation. Texas A M Univ, Texas

Salisbury JW 1986. Preliminary measurements of leaf spectral reflectance in the 8-14 μm region. *Int J Remote Sens* **7**:1879–1886

Salisbury JW, Milton NM 1988. Thermal infrared 2.5-to 13.5-μm) directional hemispherical reflectance of leaves. *Photogramm Eng Remote Sensing* 54:1301–1304

Sankaran, S., Mishra, A., Ehsani, R., and Davis, C. 2010. A review of advanced techniques for detecting plant diseases. *Comput. Electron. Agric*. **72**, 1–13. doi: 10.1016/j.compag.2010.02.007

Schulze ED, Beck E, Müller-Hohenstein K 2002. Pfl anzenökologie. Spektrum Akademischer, Heidelberg

Sims DA, Gamon JA 2002) Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. *Remote Sens Environ* **81**:337–354. https://doi.org/10.1016/S0034-4257(02)00010-X

Sinclair TR, Ludlow MM 1985. Who taught plants thermodynamics? The unfulfilled potential of plant water potential. *Funct Plant Biol* 12:213–217

Stagnari, F., Galieni, A., Speca, S., Cafiero, G., and Pisante, M. 2014. Effect of light and water supply on morphological and physiological leaf traits of red beet. *Agron. J.* **106**, 459–468. doi: 10.2134/agronj2013.0293

Stellacci, A. M., Castrignana, A., Troccoli, A., Basso, B., and Buttafuoco, G. 2016. Selecting optimal hyperspectral bands to discriminate nitrogen status in durum wheat: a comparison of statistical approaches. *Environ. Monit. Assess.* **188**, 1–15. doi: 10.1007/s10661-016-5171-0

Suárez, L.; Zarco-Tejada, P.J.; Berni, J.A.J.; González-Dugo, V.; Fereres, E. 2009. Modelling PRI for water stress detection using radiative transfer models. Remote Sens. *Environ*. **113**, 730–744.

Sun, D., Zhu, Y., Xu, H., He, Y., and Cen, H. 2019. Time-series chlorophyll fluorescence imaging reveals dynamic photosynthetic fingerprints of SOS mutants to drought stress. *Sensors* **19**:2649. doi: 10.3390/s19122649

Swinerd, G., 1999, Special issue on small satellite engineering. Proceedings of the Institution of Mechanical Engineers. Part G – *Journal of Aerospace Engineering*, G4, pp. I–II.

Sylvain, T., and Cecile, L.-G. 2018. "Chapter 8: Disease identification: a review of vibrational spectroscopy applications," in Vibrational Spectroscopy for Plant Varieties and Cultivars Characterization Comprehensive Analytical Chemistry, eds J. Lopes and C. Sousa (Amsterdam: Elsevier), 195–225. doi: 10.1016/bs.coac.2018.03.005

Tucker CJ 1980. Remote sensing of leaf water content in the near infrared. *Remote Sens Environ* **10**:23–32. https://doi.org/10.1016/0034-4257(80)90096-6

Ullah S, Skidmore AK, Groen TA, Schlerf M 2013. Evaluation of three proposed indices for the retrieval of leaf water content from the mid-wave infrared 2–6μm) spectra. *Agric For Meteorol* **171–172**:65–71. https://doi.org/10.1016/j.agrformet.2012.11.014

Van Der Tol, C.; Verhoef, W.; Timmermans, J.; Verhoef, A.; Su, Z.; Observations, E. 2009. An integrated model of soil-canopy spectral radiances, photosynthesis, fluorescence, temperature and energy balance. *Biogeosciences* **6**, 3109–3129.

Vialet-Chabrand, S., and Lawson, T. 2019. Dynamic leaf energy balance: deriving stomatal conductance from thermal imaging in a dynamic environment. *J. Exp. Bot*. 70, 2839–2855. doi: 10.1093/jxb/erz068

Vinocur B, Altman A 2005. Cellular basis of salinity tolerance in plants. *Environ Exp Bot* **52**:113–122

Vorasoot N, Songsri P, Akkasaeng C, Jogloy S, Patanothai A 2003. Effect of water stress on yield and agronomic characters of peanut. *Songklanakarin J Sci Technol* **25**(3):283–288.

Wang W, Vinocur B, Altman A 2003b. Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. *Planta* 218:1–14.

Wang, X., Hou, L., Lu, Y., Wu, B., Gong, X., Liu, M., et al. 2018c. Metabolic adaptation of wheat grain contributes to a stable filling rate under heat stress. *J. Exp. Bot*. 69, 5531–5545. doi: 10.1093/jxb/ery303

Wiegand CL, Richardson AJ, Escobar DE, Gerbermann AH 1991. Vegetation indices in crop assessments. *Remote Sens Environ* **35**:105–119.

Wieneke, S.; Ahrends, H.; Damm, A.; Pinto, F.; Stadler, A.; Rossini, M.; Rascher, U. 2016. Airborne based spectroscopy of red and far-red sun-induced chlorophyll fluorescence: Implications for improved estimates of gross primary productivity. *Remote Sens. Environ*. **184**, 654–667.

Xue, J., and Su, B. 2017. Significant remote sensing vegetation indices: a review of developments and applications. *J. Sens.* 1–17. doi: 10.1155/2017/1353691

Yao, J., Sun, D., Cen, H., Xu, H., Weng, H., and Yuan, F. 2018. Phenotyping of Arabidopsis drought stress response using kinetic chlorophyll fluorescence and multicolor fluorescence imaging. *Front. Plant Sci.* **9**:603. doi: 10.3389/fpls.2018.00603

Young, S.J.; Johnson, B.R.; Hackwell, J.A. 2002. An in-scene method for atmospheric compensation of thermal hyperspectral data. *J. Geophys. Res*., **107**, 4774.

Zarco-Tejada PJ, Miller JR, Noland TL et al 2001. Scaling-up and model inversion methods with narrowband optical indices for chlorophyll content estimation in closed forest canopies with hyperspectral data. *IEEE Trans Geosci Remote Sens* 39:1491–1507. https://doi.org/10.1109/36.934080

Zhang N, Wang M, Wang N. 2002. Precision agriculture -a worldwide overview. Computers and Electronics in *Agriculture*, **36**, 13–132.

Zhang, J., Huang, Y., Pu, R., Gonzalez-Moreno, P., Yuan, L., and Wu, K. 2019a. Monitoring plant diseases and pests through remote sensing technology: a review. *Comput. Electron. Agric*. **165**:104943. doi: 10.1016/j.compag.2019.104943

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Research Article

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The Impact of Forest Products Demand on Deforestation in Rwanda: A Case Study of Burera, Gakenke, Gicumbi, Musanze, and Rulindo Districts

Gaspard Ntabakirabose[1], Clementine Mukanoheri[2], Spridio Nshimiyimana[3], Felicien Ndaruhutse[4], Jean Claude Tuyisenge[5], Protais Musoni[6], David Mwehia Mburu[7]
[1,2]Forest Research Department, Rwanda Forestry Authority, Huye, Rwanda
[3]Forest Management Department, Rwanda Forestry Authority, Huye, Rwanda
[4]Impact Product and Brand Department, One Acre Fund, Kigali-Rwanda
[5,6]Agriculture and Natural Resource Department, Ministry of Local Government, Musanze, Rwanda
[7]Department of Land Resources Planning and Management, College of Agriculture & Natural Resources, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya
**Corresponding author e-mail: gmutago@gmail.com*
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ABSTRACT
The world's forests play an integral role in not only the well-being of their inhabitants but also in the overall health of other lifeforms on the planet. Some of the major benefits of forests include climate stability, ecological benefits, biodiversity and economic importance. Deforestation is one of the major challenges to gain the above benefits in the long run. It involves the permanent end of forest cover to make that land available for residential, commercial or industrial purposes. The purpose of this study was to assess the impact of forest products demand on deforestation in Rwanda. A case study of Burera, Gakenke, Gicumbi, Musanze, and Rulindo Districts. The study adopted a cross-sectional survey research design as its framework to guide the process of data collection. The target population was households living closer to the forest products demand. The study adopted a purposive sampling approach to select five districts. Twelve (20) households were randomly selected from each sector making a total sample size of 120 respondents. Descriptive analysis was done using SPSS version 20, and regression using STATA version 12. The results of the study indicated that the forest products used by the households were firewood, stakes, timbres, charcoal, building scaffolds, fodder, poles, and medicine. The results of the logit model showed that land size, family income, household size, occupation, education level, and fodder were statistically significant and positively influenced forest product demand in the study area at ($p< 0.01$). The result of the regression analysis also revealed that eight variables out of nine were positively significant and influenced deforestation in the study area. Agricultural activities, urbanization, forest fires, and overpopulation were statistically significant at the $P \leq 0.01$ level. Despite the roles provided by forests all over the world, the results of this study showed deforestation effectively causes climate change, wildlife extinction & habitat loss, decline in the life quality of people (100%). After these results of the study, the best solution to overcome deforestation is to curb the felling of trees by enforcing a series of rules and laws to govern it. Supporting research, extension and training for more sustainable grazing systems, including silvopastoral techniques that can simultaneously increase livestock production and protect the soil against nutrient depletion, compaction and erosion.
Keywords: Impact, Forest Products, Demand, Deforestation.

INTRODUCTION
Human beings through their agricultural activities have affected the world environment negatively. In many forest areas, trees have been cut down by surrounding people looking for cultivable and grazing land. This has resulted too many problems related to environmental degradation such as soil erosion, soil infertility, lack of firewood, lack of fodder, lack of timber, and lack of raw materials (Shackleton CM, *et al.,* 2007). The practice of agroforestry is viewed to offer solutions to the above problems. Forest resource utilization poses a major challenge to the delicate balance between complex and fragile ecosystems in many developing countries.
About 60 percent of the world's forests approximately 2.4 billion hectares are primarily or partially used for the production of wood and non-wood forest products. Wood fuel, including charcoal, accounts for about half of total global round wood production, and industrial round wood for the other half. Most wood fuel is used in

its country of production, particularly in rural areas and in developing countries, for heating and cooking, usually on open fires or in simple cookstoves (FAO, 2007). In Africa, more than two-thirds of the population relies partly on forest products to satisfy their livelihood needs (Duncan Brack, 2018). Aside from timber, NTFPs play an important role in providing between 29–39% of food, medicine, and income needs to about 80% of the local populations living in forest areas of Central Africa (Ayotebi, O, 2000).

The Republic of Rwanda is a landlocked country in the East African region, with an area of 26,338 km² and an estimated population of 12 million in 2017. Rwanda has an equatorial climate mainly modified by relief with constant annual temperatures ranging from 16 to 24°C and annual rainfall between 700mm and 1,400 mm in the drier areas and reaching 2000 mm in the wetter western provinces (NISR, 2012). Currently one of the limitations facing Rwanda is its high population density (estimated at 490 persons per km2), which impacts heavily on the fragile limited land resource characterized by the hilly terrain, high rainfall, and erodible soils. In addition, the country's population growth rate estimated at 2.27% in 2017 is a threat to the sustainability of the natural resource base (NISR, 2012).

Rwanda is characterized by steep topography. Despite having almost 30% forest cover, the high population density of 490 people/Km² means land is very intensively used. Around 50%2 of the population is under 20, which is growing at 2.6% annually. The Agriculture sector provides 68%3 of the employment with small-scale farming predominating (NISR, 2012). Today, Rwanda has about 704,997 hectares of land with forest and shrub land cover, equivalent to 29.6% of the country, of which 17.7% are plantation forests and 11.9% are natural mountain forests and Savannah shrub land protected in national parks, including Nyungwe forest in the south-west, Gishwati & Mukura forests in central-west, Volcanoes forest in north and Akagera savannah shrub in East (MINILAF, 2017).

The 2012 forest cover mapping of Rwanda from Orthophotos, defined forests based on the ability to map them as a group of trees higher than 7 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ on a land area of 0.25 ha or more (FAO and UNEP,2020). Differentiation of forests into categories shows that the total forest area comprised 18% natural forests (123,538 ha), 39% shrublands (260,569 ha), and 43% (286,811 ha) forest plantations (FAO and UNEP,2020).

Rwanda's forests contribute greatly to the national economy. In the fiscal year 2016/17, the contribution of forestry to the GDP was estimated to be US$365 billion (i.e. 5% of the total GDP) (NISR, 2015). Forests have a significant role to play in Rwanda's national development. They provide 86% of the primary energy source mainly as domestic cooking energy. They hold the base for the country's tourism opportunities, which in 2013 generated US$ 294 million and are targeted to increase to over US$ 600 million by 2020. Rwanda's forests protect watersheds and downstream wetlands, supporting agriculture, which accounts for 36% of GDP, 80% of employment and generates more than 45% of the country's export revenues (NISR, 2014).

This economic value though is not fully quantified, but translated into tangible assets like wood consumption (construction, sawing, domestic and industrial energy), fruit sales, erosion control, etc., and in ecosystem services such climate, quality of landscape, tourism, recreation etc., forests and trees are now highly valued for the role they play in providing these benefits (MINILAF, 2017). They are better integrated with other land uses, providing a safe habitat and network for biodiversity, and supporting the rural industries while at the same time, maintaining the climate of Rwanda. Healthy forests, woodlands, and trees can help to provide clean water from well-managed supplies, resilient ecosystems, and good air quality (MINILAF, 2017). It is expected that by 2020, Rwanda's population will climb from 12 million registered in 2017 to 13.5 million and towards 26 million by 2050 of which about 35% will live in Kigali city and in the towns of Rwanda. This will put substantial pressure on Rwandan forests for wood construction and wood energy (https://news.mongabay.com, 2012).

The new threats and challenges to Rwanda's forests today demand new information about species choice, woodland management and restoration, land use and management, pest epidemiology, and control. There is a need to ensure that the resilience and adaptability of forest ecosystems to the changing climate is understood, and considered essential for the continuance of the crucial services that forests provide to Rwandan society (MINILAF, 2017). Climate change and global warming due to greenhouse gas emissions are a reality. The climate of Rwanda is expected to change towards a warmer and wetter climate by 2050. Although Rwanda, has one of the lowest emissions in the world, continuous deforestation to meet the timber and energy demands of a growing population, coupled with uncontrolled forest land use change to agricultural and human settlements6, will put a large part of Rwandan land into degradation and the cost of inaction will be higher than the cost of action in due time (MINILAF, 2017).

There is a severe and increasing gap between wood supply and demand, which is more than twice the sustainable supply. Shortage of fuelwood drives forest degradation in public forests while private forests are often seriously overcut; both these factors prejudice future productivity (Mfon, P *et al.*, 2014). An analysis of the wood demand and supply shows that the demand-to-supply ratio is 2:1 and the shortage is projected to increase in the future unless alternative sources of wood energy are sought. The consumption of fuelwood for Rwandan households is estimated at 2.7 million tonnes per year and charcoal-making accounts for about 50% of total fuelwood used (RNRA-DFNC, 2015). The Business-as-usual scenario on wood supply/demand

estimates the deficit between wood supply and demand to be 4.3 million tonnes (oven dry weight) in 2017, which is projected to increase to 7.5 million tonnes by 2026. This is due to a high increase in demand for firewood and wood for charcoal. This must imply over-exploitation of already low-stocked forests (RNRA, 2014).

Many factors contribute to the demand for wood products. These include population, not just its overall size but its rate of growth, levels of urbanization, migration and changing age structures. The population density in any given country, particularly density per unit of forest, provides a good indication of the pressure on the country's forests (FAO, 2007). Increases in working-age populations and levels of urbanization tend to increase the demand for housing and wood products used in construction and furnishing, though urbanization can also reduce demand for wood fuel, as access to electricity and alternative forms of heating is generally easier in urban than in rural areas (FAO, 2007).

Demand for wood products is significantly affected by changes in income. All else being equal, increasing income tends to be associated with rising demand for wood products (apart from wood fuel), particularly those used in construction and housing (FAO, 2007). More than 1.6 billion people worldwide almost a quarter of the global population depend on forests for food, medicines and fuel, as well as their jobs and livelihoods, and 200 million people, including many indigenous people, directly depend on forests for their survival (FAO, 2007). Pressures from the rising population have extended farming onto unsuitable land, and have driven deforestation. More than 95% of the rural population relies on wood for fuel, and the national dependency level is over 85% despite strong efforts to reduce this (Mfon, P *et al.*, 2014).

Deforestation is the conversion of forested areas to non-forest land use such as arable land, urban use, logged area, or wasteland. According to FAO, deforestation is the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold. Deforestation can result from deliberate removal of forest cover for agriculture or urban development, or it can be an unintentional consequence of uncontrolled grazing (which can prevent the natural regeneration of young trees). The combined effect of grazing and fires can be a major cause of deforestation in dry areas. Deforestation implies the long-term (>10 years) or permanent loss of forest cover (GIRI TEJASWI, 2007).

Deforestation defined broadly can include not only conversion to non-forest but also degradation that reduces forest quality - the density and structure of the trees, the ecological services supplied, the biomass of plants and animals, the species diversity, and the genetic diversity. The narrow definition of deforestation is the removal of forest cover to an extent that allows for alternative land use. The United Nations Research Institute for Social Development (UNRISD) uses a broad definition of deforestation, while the Food and Agriculture Organization of the UN (FAO) uses a much narrower definition (Hosonuma N, 2012).

Deforestation has been attributed to socio-demographic factors, such as population growth and the political economy of class structure, and specific exploitation activities like commercial logging, forest farming, fuel wood gathering, and pasture clearance for cattle production. Deforestation from logging operations, particularly in stands of tropical moist forest, is often claimed to occur in a two-step sequence. First, loggers build roads into primary or old-growth forests and remove selected trees. In many places of the world, it was observed that the logging operation destroys 45-74% of the residual trees. The logging damage, however, is compounded once the loggers have left (Hosonuma N, 2012).

The most important direct causes of deforestation include logging, the conversion of forested lands for agriculture and cattle raising, urbanization, mining and oil exploitation, acid rain and fire. In other countries, clear-cut logging practices have been the main reason for forest loss (GGCR, 2011). Probably the most serious and most shortsighted consequence of deforestation is the loss of biodiversity. The negative consequences of global warming are catastrophically increasing drought and desertification, crop failures, melting of the polar ice caps, coastal flooding, and displacement of major vegetation regimes (GGCR, 2011).

Technological change also affects demand as the main cause of deforestation; this includes developments in wood processing technology allowing improved rates of recovery the use of small-dimension timber, and improvements in reuse and recycling. As well as producing wood and non-wood products, forests provide solutions to challenges including poverty eradication, environmental sustainability, food security and agriculture, energy, clean water and watershed protection, biodiversity conservation, climate change, desertification and land degradation, and disaster risk reduction (FAO, 2007).

The main drivers of deforestation and forest degradation in Rwanda are agriculture, with 95% of households practising traditional subsistence agriculture on small plots that have degraded soil structure and fertility due to continuous cultivation (Rishi P, 2007), infrastructure development, Urbanization including the growing of built-up area, which increased by over 300% in the period from 1990 to 2016 (R. Uma Shaanker,2004). Artisanal mining practices, with a high increase in issued mining permits (in 2014 a total of 548 mining permits were issued to 213 registered mining entities (R. Uma Shaanker,2004) but no restoration of abandoned mining sites, forest product extraction, mostly firewood, charcoal, and timber and limited forestry extension services (An L, 2002).

Forestry is a source of livelihood for many farmers and rural households in developing countries, especially in Sub-Saharan Africa (Cavendish, W. 2000; Abebaw D, 2007). However, the utilization of fuelwood in Rwanda

contributes greatly to desert advancement and consequently has implications concerning climate change. Yet, few people understand the drivers and dynamics of fuelwood consumption in Rwanda and other African countries (Abebaw D, 2007; Bart Muys, 2020). Evidence from China, another developing country, indicates that a considerable majority of households in the Wolong region remain dependent on fuelwood despite their access to electricity.

Forests in such economies are major sources of livelihood for the rural communities that depend on forest resources for fuel wood, construction material, and livestock grazing, among others. The extraction of biomass in the form of forest products like timber, fuelwood, and fodder alters wildlife habitat and constitutes one of the most important threats to forests and wildlife (Prasad, *et al.*, 2015). At the same time, an increase in the populations of communities surrounding forests increases the demand for forest resources, which in turn leads to an increase in degradation. Other factors associated with the increase in forest degradation broadly include demographic, economic, institutional, and technological factors (REMA, 2009; FAO, 2007).

Despite the above measures, the negative effects of forest products demand on deforestation seem to increase due to poor or non-adoption of measures. Such practices like continuous cropping, mono-cropping, overgrazing of farmland, bush burning, use of heavy machines and tools to till the land and use of inorganic fertilizer and chemical pesticides and herbicides are still in practice. There is doubt whether farmers are aware of the forest degradation effects of these farming practices employed or perhaps the farmer's socioeconomic factors are constraints to the adoption of these measures. The purpose of this study was to find out the impact of forest product demand on deforestation in Rwanda. A case study of Burera, Gakenke, Gicumbi, Musanze, and Rulindo Districts. The specific objectives were to identify the forest products demanded by households in the study area, to analyze the factors influencing forest product demand in the study area, to analyze the factors influencing deforestation in the study area, and to determine the impact of deforestation on human livelihood in the study area.

MATERIALS AND METHODS

Description of the Study Area

Northern Province is one of Rwanda's five provinces. It was created in early January 2006 as part of a government decentralization program that reorganized the country's local government structures. Northern Province comprises most of the former provinces of Ruhengeri and Byumba, along with northern portions of Kigali Rural. It has a Surface Area of 3293.3 km^2 and it is composed of five namely Burera, Gakenke, Gicumbi, Musanze, and Rulindo.

(NISR, 2012). The Northern Province shares its Eastern border with the Eastern Province, it borders Uganda in the Northern, shares its Western border with the Western province, while Kigali city and the Southern province border in the Southern part. The 4th Rwanda Population and Housing Census (PHC4) has enumerated 1,726,370 residents in the Northern Province, which represents 16.42% of the total population of Rwanda (10,515,973 residents) (ngm.nationalgeographic.com, 2009).

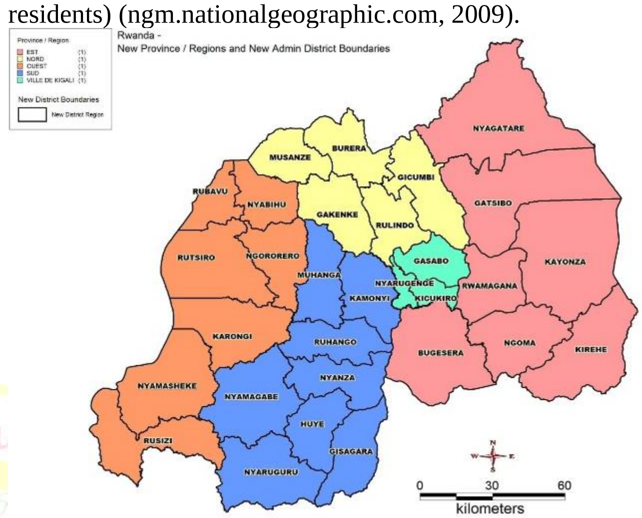

Figure 1. Administrative Map of Rwanda

Research Design

Research design provides a logical structure for research data gathering and analysis (Bryman, 2008). The study adopted a cross-sectional survey research design as its framework to guide the data collection process. According to Bryman (2008), cross-sectional survey research design is the collection of data mainly using questionnaires or structured interviews to capture quantitative or qualitative data at a single point in time.

Target Population, Data Collection, and Sampling Procedure

The target population was households living closer to the forest products demand. The study adopted a purposive sampling approach to select five districts such as Burera, Gakenke, Gicumbi, Musanze, and Rulindo of Northern Province of Rwanda within these ten sectors (Butaro, Cyanika, Gakenke, Muzo, Byumba, Kageyo, Muhoza, Cyuve, Shyorongi, and Buyoga) were selected based on high number of population and households within sector demanding high quantity of forest products for their livelihoods. The respondents were stratified into one category namely forest products users. Twelve (12) households were randomly selected from each sector making a total sample size of 120 respondents. Data was collected between July-September June 2021 through personal interviews using pretested questionnaires. The information collected included bio-data and information relating to the forest products demand and deforestation.

Data Analysis

The study used structured questionnaires to obtain information from the respondents. The data was coded and entered into the Statistical Package for Social Scientists (SPSS). Descriptive analysis was done using SPSS version 20, and regression using STATA version 17. The analysis included the assembling of tables and a logistic regression analysis to determine factors that influenced

household forest product demand and deforestation in the Northern Province of Rwanda.

Table 1. Sample Size Distribution.

Local Government Areas/District	Local Government Areas/Sector	Sample size
BURERA	Butaro	12
	Cyanika	12
GAKENKE	Gakenke	12
	Muzo	12
GICUMBI	Byumba	12
	Kageyo	12
MUSANZE	Muhoza	12
	Cyuve	12
RULINDO	Shyorongi	12
	Buyoga	12
TOTAL		120

Model Specification

To examine households' forest products demand and deforestation in the study area, a logistic regression model was mostly adopted for this study. The study regressed household forest product demand and deforestation as dependent variables as a function of the independent variables which are socioeconomic and demographic. The choice of the logistic regression model is premised on the specification of the dependent variable as binary in nature and outcome.

Logistic Regression

Following Maddala (1983, 2001), the probability, *p*, that a household uses forest products is given by:

$$P = \frac{e^{z}}{1+e^{z}}$$

Central to the use of logistic regression is the logit transformation of p given by Z

$$Z = \ln\left(\frac{p}{1-p}\right)^{2}$$

Where;

$$Z = Z\left(f, d, a\right) + \varepsilon$$

Z is a latent variable that takes the value of 1 if the household used forest products and 0 otherwise, f is a vector of farmer characteristics, d is a vector of farm-level variables, a is a vector of asset endowment variables, and ε is the stochastic term assumed to have a logistic distribution. Based on the above equation, the logistic regression model was estimated using multiple regression analysis.

Estimated Logistic Model

Specifications of the Empirical Model used for the forest products (Z) = f (age, household size, educational level, major occupation, membership of cooperative, farming experience, farm size, extension contact, gender, marital status, distance forest) + e

Specifically, the empirical model is specified as:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + e$

Where:

Y represents the total forest products demanded in store (st)

X_1 = Age (years)

X_2 = Household size (number of persons in the household)

X_3 = Educational level (years spent in school)

X_4 = Major occupation (Dummy, farmer = 1, off-farming = 0)

X_5 = Membership of cooperative (Dummy, yes = 1, no = 0)

X_6 = Farming experience (years)

X_7 = Farm size (hectares)

X_8 = Extension contact (number of monthly visits)

X_9 = Gender (Dummy, male = 1, female = 0)

X_{10} = Marital status (Dummy, married = 1, other = 0)

X_{11} = Distance from forest (km)

e = Error term

β_0 = Intercept

RESULTS AND DISCUSSIONS

This study discussed the results and findings as well as the linkage to the previous parts. The first results relate to the sociodemographic characteristics of households surveyed within the selected sectors/communities under study as shown in Table 1 below.

Socio-economic Characteristics of Respondents Sampled

The data collected from the respondents were used to run regression analysis as well as to find out the relationship between inputs and output. The results obtained are shown in table 4.1 below.

Table 2. Socio-economic characteristics of survey respondents.

	Frequency	Percentage
Gender		
Male	69	57.5
Female	51	42.5
Age		
21-30	16	13.3
31-40	30	25
41-50	52	43.3
>50	22	18.4
Family size		
1-3	20	16.7
4-7	61	50.8
8 and above	39	32.5
Education		
Illiterate	52	43.3
Primary	73	60.8
Secondary school	29	24.2
Vocation	12	10
University	6	5

The study indicated that 57.5% of the respondents were male and 42.5% were female. This implies that most of those who participated were male and were the most likely to participate in forest product use and

conservation. The findings displayed that 43.3% of the respondents are in the range of between 41-50 years old followed by 25% whore are in the range between 31-40 years. The third class is 50 years and above with 18.4%. The last class was that is in the range between 21-30 years with 13.3%. The findings showed that 50.8% of the respondents are in the range of between 4-7 members of a household followed by 32.5 with eight and above members per household. The last class was in the range between 1-3 members with 16.7%. This plays a very significant impact on product use and its conservation due to the supply of labor from the same household and that minimizes the costs of labor from outside the family. This was supported by studies like Seidu [48] which emphasize those large households are better at providing free labor, indicating the usefulness of larger households in improving farm efficiency. Results also pointed out that the majority of respondents in the study area are not educated. The results showed that 43.3% are illiterate, followed by 34.2% of those who studied primary school and the last is the respondents have university studies with 2.5%. The high percentage of no educated farmers should harm better use of forest products and conservation through harvesting, collection, and long-time to understand different better advice given by forest officers, agronomists, and other advisors of forests and environment management like forest practices such as pruning, thinning, pollarding and coppicing that control facilitate the conservation of forests in the study area.

Types of Forest Products Demanded by Households in the Study Area

The forest products used by the households were firewood, stakes, timbres, charcoal, building scaffolds, fodder, poles, and medicine (table 1). By considering the responses from respondents all the users of forest products, 55% used firewood followed by stakes with 22% while other products were used by less than 20% of the households. The least used product was medicine, which was used by 0.8% of the households.

Table 3. Types of forest products demanded by households in the study area.

Products used	Frequency	Percentage (%)
Firewood	55	45.8
Stakes	22	16.7
Timbers	17	14.2
Charcoal	10	8.3
Building scaffold	8	6.7
Fodder	5	5.8
Poles	2	1.7
Medicine	1	0.8
Total	120	100

Factors Influencing Forest Products Demand

The results of the logit model show that land size, family income, household size, occupation, education level, and fodder statistically significantly and positively influenced forest product demand in the study area ($p< 0.01$). While, gender, stakes, and distance to market indicated a positive influence of forest product demand in the study area at 5%. Therefore, a unit increment in the area under forest increases the likelihood of using forest products by 0.210, holding other factors constant. This suggests that farmers accessing larger pieces of land are likely to set aside part of their land for forest plantation. The findings also indicated that household size significantly influences the forest products demand in the study area at ($p< 0.01$). This is because the larger household sizes are prone to have more members available to require resources from the forest especially firewood for their daily food cooking.

The results showed that family income also positively and significantly influenced household forest product demand in the study area. Moreover, households with higher income usually have a strong purchasing power that enables them to buy more food to compensate for low harvest while the low-income households rely heavily on natural resource extraction from forestlands around them (Tiziano Gomiero, 2016). Infrastructure is expected to influence the ease of accessing places and facilities such as markets. Therefore, if distances to such facilities are large, the likelihood of using forest products for sale may be less. This was supported by Mulenga *et al.*,(2014) who reported that returns on labor and agricultural income are higher among communities that are closer to markets hence making them better off than their rural counterparts. This implies that the higher rural wages and greater off-farm employment opportunities reduce reliance on environmental resources.

Results further showed that the main occupation of the household head influences the use of forest products. The households practising farming as the main occupation were more likely to use forest products than those whose main occupation was off-farm. This is due more particularly to too many stakes used in farming climbing beans, and fodders used for livestock farming without forgetting timbres and woods used in building animal houses in the study area. In addition, the results showed that income influences the use of forest products. An increase in income has a positive influence on the likelihood of forest product use. This finding is in line with the findings of Hedge and Enters (2000) who indicated that higher-income groups utilize more forest resources than lower-income groups when no forest use restrictions are in place. However, it is in contrast with the findings of most past studies (Seidu A, 2008; Vedel, *et al.*,2004) that suggest that as incomes increase the likelihood of dependence on forests declines. The probable reason for the positive relationship is the lack of alternatives for fuel wood in the study area due to remoteness. Households have to cover long distances to get cooking gas, or those who cannot get cooking gas make use of firewood more attractive than the households with the capacity to get it.

The results of the study revealed that the education level of household heads also positively and significantly influenced household forest product demand in the study area. This is because the income obtained from other

economic activities could be used by the educated household with a higher education level, to engage in the commercial exploitation of forest products. This was supported by the study of Newton *et al.*, (2016) indicated that the level of education attained by the household head is expected to influence the nature of his/her economic activity and consequently the level of his/her income. However, this study was contrasted by the study of Newton *et al.*, (2016) who assumed that the high level of education of respondents would lead to the extraction of fewer forest products since education opens up alternative employment opportunities and diverts people from subsistence livelihoods activities such as the gathering of NTFPs from the forest reserve. This is because education would make it easier for households to comprehend negative externalities and passive user values of natural resources.

The results of this study indicated that the gender of the household head influenced the use of forest products. This implies that a 1% increase in women household heads would increase forest product demand by 0.2%. This is due more particularly to traditional culture in the study area influencing a high number of women participating in the collection of forest products and daily food cooking. While the collection of woods for timbers, carpenters, woof for making charcoals, and woods for building is exclusively done by men. This was supported by Jagwe *et al., (*2010) reported that male-headed households are more likely to sell farm products because they own more productive resources than female-headed households.

The study findings also reveal that there is a negative and significant relationship between age, timber diversification, distance to the forest, and likelihood of using forest products. The results showed that the closer the location of the forest to the household the more likely respondents would demand forest products than those located far from forest. This implies that a 1km increase in distance to the forest would reduce forest product demand by 1.045%. The results were supported by Tafere (2013) in his study concerning age, household size, and location of the forest showed that age had a positive relationship with participation in forest management. It was also supported by Cavendish (2000) had earlier stated that older people have difficulty carrying out arduous tasks related to NTFP collection activities.

Factors Influencing Deforestation in the Study Area

The data collected from the respondents were analyzed using a logit obit regression model to find out the factors influencing deforestation in the study area. R-square value (R^2) of 0.8925% means that 89.5% of the total variation in factors influencing deforestation explained the dependent variable. The result of the regression analysis in (table 5) showed that eight variables out of nine were positively significant and influenced deforestation in the study area. Agricultural activities, urbanization, forest fires, and overpopulation were statistically significant at the $P \leq 0.01$ level. Livestock ranching and desertification of land were significant at $P \leq 0.05$ level while mining and price of related fuel were significant at 10% level. Moreover, only illegal logging was not significant in influencing deforestation. This was supported by Otum, *et al.*, (2017) state that most of the activities that can lead to deforestation are human-initiated and are for economic purposes. They also add that forest exploitations are done on two levels: firstly, by local people for survival and livelihood, and secondly, on a more commercial level that involves commercial logging, land conversion for agricultural purposes

Table 4. Logit Regression analysis of the Factors Influencing Forest Products demand.

Explanatory variables	coefficient	Standard deviation	p-value
Land size	0.210	0.388	0.001
Family income	0.325	0.182	0.008
Households size	0.018	0.207	0.004
Age	-0.091	0.059	0.007
Gender	0.164	0.150	0.025
Occupation	0.256	0.065	0.000
Education level	0.088	0.058	0.001
Distance from forest	-1.045	0.357	0.000
Distance to market	0.139	0.430	0.037
Timber diversification	-3.961	2.556	0.050
Fodder	0.719	0.410	0.000
Stakes	0.635	4.127	0.045
constant	1.770	2.152	0.000
Number of observations:120	Prob> chi2:0.0000		
Log-likelihood = -83.374	Pseudo R2:0.7407		

The results indicated that agricultural activities had a positive influence and statistically significant on deforestation in the study area at ($p< 0.01$). This implies that a unit increase in agricultural activities will lead to increased deforestation by 0.8 units. As earlier mentioned in the results of forest products demanded in the study area, agricultural activities are one of the significant factors affecting deforestation. This is supported by Karamage F *et al.,* (2004) indicated that agriculture leads to around 80% of deforestation. Due to the overgrowing demand for food products, a huge amount of trees are felled to grow crops, and 33% of agriculture-caused deforestation is because of subsistence agriculture.

This was also supported by Karamage F *et al.*, (2004) which notes that industrial activities are the principal driver of deforestation and degradation worldwide, but subsistence agriculture and fuelwood consumption remain an important direct driver of deforestation, especially in Africa. Drivers vary on a regional scale. For example, cattle ranching and large-scale agriculture are major drivers of deforestation in Latin America, whereas

palm oil development, intensive agriculture, and pulp and paper plantations are principal drivers in Indonesia.

The results showed that there is a statistically significant association between urbanization and deforestation in the study area at ($p< 0.01$). This implies that a unit increase in Urbanization would increase deforestation by 1.54 units. This is because the construction of for instance houses, bridges, and roads is undertaken; here again, trees are chopped to build roads. Overpopulation too directly affects forest cover, as with the expansion of cities, more land is needed to establish housing and settlements. Therefore, forestland is reclaimed. Ogundele, *et al.*, (2016) also add urbanization, industrialization, infrastructural development, tourism, bush burning, mining, logging and fuelwood collection, corruption, and political causes as some causative factors responsible for deforestation.

The results revealed that there is a statistically significant association between forest fires and deforestation in the study area at ($p< 0.01$). This implies that a unit increase in forest fires would increase deforestation by 4.2 units. This for example would be forest blazes where hundreds of trees are lost each year due to forest fires in various portions of the world. It happens due to extremely warm summers and milder winters. Fires, whether caused by man or nature, result in a massive loss of forest cover (S. M. Jua´rez-Orozco *et al.*, 2017) also supported). Forest fires extensively affect vegetation cover, density, structure, composition, diversity, and productivity. They result in deforestation, reduction in population sizes, forest edge effects, changes in the community structure, and the immigration of exotic species.

The results also pointed out that there is a statistically significant association between overpopulation and deforestation in the study area at ($p< 0.01$). This implies that a unit increase in overpopulation would increase deforestation by 0.6 units. This is because overpopulation requires more land to establish housing and settlements. It generates a significant need for food and farmland to grow food and raise livestock. It automatically requires many more roads and highways for transport and communication all these results in deforestation. Logging industries cut down trees for furniture, building materials, and many more products. This was supported by Mfon, *et al., (*2014) in their study in Nigeria who have identified population growth and its resultant effect on deforestation. This is because as the population grows, it increases the pressure on the available forest resources for sustenance and survival. In addition, population growth also increases the demand for housing and construction, which results in a general forest decline.

Increases in human population are likely to increase household size and this could lead to an increase in fuel wood dependence in developing countries. Kapinga (2015) argued that the majority of these households who depend on the forest for their livelihood are from the rural periphery of developing countries and this has led to deforestation as a common feature.

Bamba, *et al.*, (2011*)* opine that deforestation is usually caused by agricultural practices, timber exploitation, and charcoal and firewood consumption, and these factors are exacerbated by population growth. Population growth harms the available forest cover thus deforestation. Economic growth is among the causes of deforestation because it can also result in the expansion of urban areas especially in Nigeria resulting in the need for raw materials needed for construction (Oyetunji Po *et al*.,2020).

The results revealed that there is a significant association between Livestock Ranching and forest degradation and deforestation in the study area at a 5% level. This implies that a unit increase in Livestock Ranching would increase deforestation by 1.1 units. Livestock production compounds the damage to forests. In a few short years, overgrazing, compaction and nutrient loss turn cleared forestlands into eroded wastelands (GGCR,2011). This is because livestock farmers often clear the land by cutting down trees and burning them to raise livestock and grow food and fodders. They continue to use the property until the soil is completely degraded and repeat the same process on new woodland. Livestock especially is believed to be responsible for about 41% of global deforestation (Jagwe, J *et al.*, 2010).

The results also indicated that there is a significant association between desertification of land and deforestation in the study area at a 5% level. It implies that a 1% increase in the desertification of land would increase deforestation by 0.4%. This should occur due to land abuse, making it unfit for the growth of trees. Many industries in petrochemicals release their waste into rivers, which results in soil erosion and makes it unfit to grow plants and trees. This was supported by AGNS (2022) reported that desertification has led to a reduction in agricultural productivity and incomes; it has also contributed to the loss of biodiversity in many dryland regions. It is further projected to cause reductions in crop and livestock productivity, modify the composition of plant species and reduce biological diversity across drylands. In sub-Saharan Africa particularly, crop production may be reduced by 17–22% due to climate change by 2050 AGNS (2022). Desertification amplifies global warming through the release of CO_2 linked with the decrease in vegetation cover. This decrease in vegetation cover tends to increase local albedo, leading to surface cooling (AGNS, 2022).

The results also indicated that there is a significant association between mining deforestation in the study area at 10% level. It implies that a 1% increase in mining would increase deforestation by 0.2%. It is because the mining of gold and wolfram for example requires a considerable amount of forestland. Apart from this, roads and bridges have to be built to make way for trucks and other equipment. The waste that comes out from mining pollutes the environment and affects nearby species, particularly forest degradation. This was supported by REMA (2015). Showed that mining is a non-renewable resource activity with great potential.

However, although it utilizes a small area of the land it can have significant and often irreversible environmental impacts.

Mining can have harmful effects on the surrounding surface and groundwater. If proper precautions are not taken, unnaturally high concentrations of chemicals, such as arsenic, sulphuric acid, and mercury can spread over a significant area of surface or subsurface water (Newton P *et al*, 2016).

The lifecycle of is one of the filthiest cycles that causes deforestation due to the number of toxins, and heavy metals that are released soil and water environment (Oyetunji *et al*, 2020). Although the effects of mining take a long time to affect the environment the burning and fires, which can burn for up to decades can release flying ash and increase greenhouse gasses. Specifically strip mining can destroy landscapes, forests, and wildlife habitats that are near the sites (Oyetunji *et al*, 2020). Trees, plants and topsoil are cleared from the mining area and this can lead to the destruction of agricultural land.

It was also supported by the report of Hosonuma *et al*., (2012) confirmed that indirect drivers of deforestation, including commodity prices, population trends, corruption and poor governance, land tenure, consumption, and government policies. His findings confirmed that economic growth based on the export of primary commodities and an increasing demand for timber and agricultural products in a globalizing economy are critical indirect drivers for deforestation.

Table 5. Logistic Regression Analysis of the Factors Influencing Deforestation.

Variables	Coefficients	Std. Err	P-Value
Agricultural Activities	0.814	0.061	0.000
Livestock Ranching	1.078	0.340	0.035
Illegal Logging	0.032	0.077	0.641
Urbanization	1.549	2.038	0.000
Desertification of land	0.414	3.155	0.042
Mining	0.235	3.686	0.073
Forest Fires	4.149	0.483	0.001
Overpopulation	0.603	3.016	0.000
Price of related fuel	0.971	0.807	0.068
Constant	0.4723	0.313	0.049
Number of Obs=120	Prob > chi2 = 0.0000		
Log-likelihood =-67.565	Pseudo R^2 = 0.8925		

Impact of Deforestation

Forests fulfil far more functions than simply the production of wood and non-wood products. Indeed, they are vital to achieving global sustainable development. They provide solutions to challenges including poverty eradication, environmental sustainability, food security and agriculture, energy, clean water and watershed protection, biodiversity conservation, mitigation of and adaptation to climate change, the combating of desertification and land degradation, and disaster risk reduction (Hannah Ritchie, 2021). Despite the roles provided by forests all over the world as listed by FAO above, the results of this study showed the main effects of deforestation such as climate change, wildlife extinction & habitat loss, decline in life quality of people, loss of biodiversity, food insecurity in the future, soil erosion, increase in global warming, increase in greenhouse gas emissions, floods, and acidic oceans.

The results of the study revealed that deforestation is effective because of climate change, wildlife extinction & habitat loss, decline in the life quality of people (100%). These affects the climate in many ways. Forests are the lungs of our planet. Trees take in carbon dioxide and release oxygen and water vapour in the air. When a forest is cut down, the humidity levels come down and cause the remaining plants to dry out. The drying out of tropical rainforests increases fire damage that destroys forests rapidly and harms wild animals as well as humans. In addition, Forests and climate are linked intrinsically. Forest loss and degradation are both a cause and an effect of our changing climate. At the same time, deforestation is self-perpetuating. Therefore, these occurrences are dangerous and fuel further deforestation. However, the loss of trees allows for flooding, soil erosion, desertification, and higher temperatures to occur more rapidly and exponentially. Due to the massive felling of trees, various animal species are lost. They lose their habitat and are forced to move to a new location where many of them are even pushed to extinction. This should also contribute to social economic conflict and population migration.

The results of the study also pointed out that deforestation significantly causes loss of biodiversity, food insecurity in the future, soil erosion, and an increase in global warming respectively as shown in Figure (2) below. This is because deforestation leads to a huge loss of biodiversity. About 80% of the global biodiversity is located in tropical rainforests. Forests not only provide habitats for wildlife but also foster medicinal conservation (FOA, 2016). The forest acts as a critical medium to preserve a wide variety of species. It also destroys the microbial community that is responsible for the production of clean water, the removal of pollutants, and the recycling of nutrients (Muhammad Aqeel Ashraf *et al*., 2014).

Deforestation for food may result in food insecurity in the future. Currently, 52% of all the land used for food production is moderately or severely impacted by soil erosion. In the long term, the lack of fertile soil can lead to low yields and food insecurity (Tiziano Gomiero, 2016). Trees are also crucial for our local water cycles as they keep on returning water vapour to the atmosphere. With the clearance of tree cover, the land is directly exposed to the sun, making it dry. Without trees, erosion often occurs and sweeps the land into nearby rivers and

streams. Forests serve as nature's water purification plants. Soil erosion makes soil exposed to contaminants that leach into the water supply, which damages the quality of our drinking water (CGIS-NUR/PAREF/RNRA, 2012). Trees play a major role in controlling global warming. The trees utilize greenhouse gases, restoring the balance in the atmosphere. With constant deforestation, the ratio of greenhouse gases in the atmosphere has increased, adding to our global warming woes.

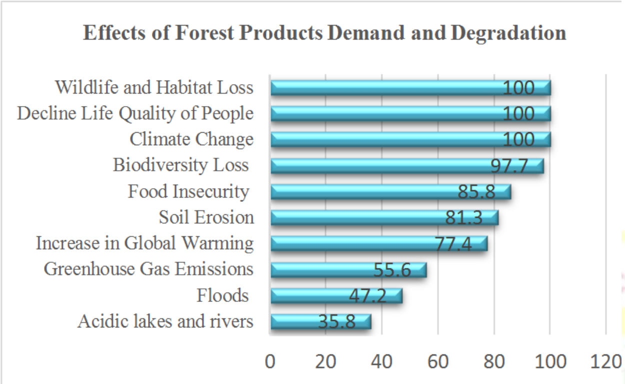

Figure 2. Effects of Forest Products Demand and Degradation on Human Livelihood.

CONCLUSION

The results of the study indicated that the forest products used by the households were firewood, stakes, timbres, charcoal, building scaffolds, fodder, poles, and medicine (table 3). The findings of the logit model showed that land size, family income, household size, occupation, education level, and fodder were statistically significant and positively influenced forest product demand in the study area at ($p< 0.01$). The result of the regression analysis in (table 5) also revealed that eight variables out of nine were positively significant and influenced deforestation in the study area. Agricultural activities, urbanization, forest fires, and overpopulation were statistically significant at the $P \leq 0.01$ level. Despite the roles provided by forests all over the world, the results of this study showed deforestation effectively causes climate change, wildlife extinction & habitat loss, decline in the life quality of people (100%). After these results of the study, the following recommendations were listed as well as to overcome the problem of deforestation:

The best solution to deforestation is to curb the felling of trees by enforcing a series of rules and laws to govern it. Deforestation in the current scenario may have reduced; however, it would be too early to assume.

Land-skinned tree cover for urban settlements should be urged to plant trees in the vicinity and replace the cut trees. In addition, the cutting must be replaced by planting young trees to replace the older ones that were cut.

Livestock rearing has become one of the leading causes of deforestation. The cut-off trees due to the need for fodder significantly increase deforestation. However, cultivating other grasses replacing trees like agroforestry trees, nipper grasses, and Kikuyu grasses will also have an extreme impact on environment management and ecosystem conservation.

There is a need therefore to invest in both formal and informal education of households in the study area where formal education raises awareness of the benefits of conserving the environment while informal education should importantly change households' attitudes towards forest conservation at a large scale.

Timber diversification activity that can help generate income in the study area may also act as an incentive to reduce reliance on forest products. Therefore, to lower the dependence on forests there is a need to improve sensitization and training on commodity value chains that could help to increase household income.

Policymakers and the private sector to invest in activities that will generate other sources of income as an important issue that will significantly reduce forest product use and empower environmental conservation.

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CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Abebaw, D. 2007. Household determinants of fuelwood choice in urban Ethiopia: a case study of Jimma town. *Journal of Developing Areas.*

Bamba1, Marjolein Visser1 & J. Bogaert. 2011. An Alternative View of Deforestation in Central Africa Based on a Boserupian Framework. *Tropicultura* **29**(4): 250-254.

Bart Muys, David Ellison, Sven Wunder. 2020. What role do forests play in the water cycle.

Cavendish, W. 2000. Empirical regularities in the poverty-environment relationship of rural households: Evidence from Zimbabwe. *World Development* Centre for International Forestry Research (CFOR. 2005. *Contributing to African development through forests strategy for engagement in sub-Saharan Africa*. CIFOR, Bogor, Indonesia.

CGIS-NUR/PAREF/RNRA. 2012. Rwanda forest cover mapping using high-resolution aerial photographs. Final Report. Huye, Rwanda

Dolisca, F., McDaniel, J. M., Teerer, L. D. and Jolly, M. C. 2007. Land tenure, population pressure, and deforestation in Haiti: The case of Forest des Pins Reserve. *Journal of Forest Economics* **13**: 277-289.

Duncan Brack. 2018. Sustainable consumption and production of forest products. Background study prepared for the thirteenth session of the United Nations Forum on Forests.

FAO and UNEP. 2020. The State of the World's Forests 2020. Forests, biodiversity and people. Rome, Italy

FAO. 2007. Cattle ranching and deforestation

FAO. 2007. Manual on Deforestation, Degradation, and Fragmentation Using Remote Sensing and GIS. Rome, March 2007

FOA. 2016. State of the World's Forests 2016 and TST Issues. Terrestrial Aquaculture: Land Use Challage and Opportunity.

GIRI TEJASWI. 2007. Strengthening Monitoring, Assessment and Reporting on Sustainable Forest Management in Asia (GCP/INT/988/JPN.

Green Growth and Climate Resilience (GGCR. 2011): National Strategy for Climate Change and Low Carbon Development.

Hannah Ritchie. 2021. Cutting down forests. What are the drivers of deforestation?

Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., Angelsen, A., & Romijn, E. 2012. An Assessment of Deforestation and Forest Degradation Drivers in Developing Countries.

https://news.mongabay.com, 2012

Jagwe, J. N., Machethe, C. L., and Ouma, E., 2010. Transaction costs and smallholder farmers' participation in banana markets in the Great Lakes Region of Burundi, Rwanda, and the Democratic Republic of Congo.

Kapinga, A. G. 2015. Impacts of REDD+ Activities to Rural Communities' Livelihood: Evidence from Kondoa Advancing REDD+ in KOLO Hills Forest Project in Tanzania, Morogoro, Tanzania.

Karamage F, Zhang C, Fang X, Liu T, Ndayisaba F, Nahayo L, Kayiranga A, Nsengiyumva JB. 2017. Modeling Rainfall-Runoff Response to Land Use and Land Cover Change in Rwanda (1990–2016. Water 9: 147.

Levang, P., Lescuyer, G., Noumbissi, D., Déhu, C. and *Developing Areas*.

AGNS. 2020. Desertification and Climate Change in Africa

An, L., Lupi, F., Liu, J., Linderman, M. A., & Huang, J. 2002. Modeling the choice to switch from fuelwood to electricity: implications for Giant Panda habitat conservation, *Ecological Economics*, 42: 445-457.

Ayotebi, O. 2000. Overview of Environmental problems in Nigeria. National Centre for Economic Management and Administration (NCEMA) Paper presented at the Conference on Environment and Sustainable Development: Ibadan.

Bamba, I; Visser, M; Bogaert, J. (Broussolle, L. 2015. Does gathering pay? Case studies from forest areas of the East and South regions of Cameroon. *Forests, Trees and Livelihoods* 16. DOI: 10.1080/14728028.2014.1000980

Mfon, P ; Akintoye, OA ; Mfon, G; Olorundami, T; Ukata, SU; Akintoye, TA. 2014. Challenges of Deforestation in Nigeria and the Millennium Development Goals. Inter. J. Environ. Bio.

MINILAF. 2017. Forest Investment Program for Rwanda.

MoE. 2019. Forestry Research Strategy and Guidelines for Rwanda (2018-2024)

Muhammad Aqeel Ashraf, Mohd. Jamil Maah and Ismail Yusoff. 2014. Soil Contamination, Risk Assessment and Remediation.

Mulenga BP, Richardson RB, Mapemba LD, Tembo G. 2011. The contribution of non-timber forest products to rural household income in Zambia. Michigan State University, Department of Agricultural, Food, and Resource Economics.

Newton P, Miller DC, Byenkya MAA, Agrawal A. 2016. Who are forest-dependent people? A taxonomy to aid livelihood and land use decision-making in forested regions. Land Use Policy.

ngm.nationalgeographic.com, 2009

NISR. 2012. Fourth Population and Housing Census, Rwanda 2012

NISR. 2014. Integrated Household Living Condition Survey (EICV 4)

NISR. 2015. Rwanda Poverty Profile Report, 2013/14

NISR. 2017. Gross domestic Product (GDP) 2016/2017.

Ogundele, AT; Oladipo, MO; Adebisi OM 2016. Deforestation in Nigeria: The Needs for Urgent Mitigating Measures. Inter. J. Geo. Environ. Mgt. 2(1)

Otum, UC; Frederick, IJ; Martina, K 2017. Tragedy of the Commons and Economics of Deforestation in Nigeria. J. Biodivers. Manage Forestry, 6:1.

Oyetunji, Po; Ibitoye, Os; Akinyemi, Go; Fadele, Oa; Oyediji, Ot. 2020. The Effects of Population Growth on Deforestation in Nigeria: 1991 – 2016

Prasad, Siva, T Byragi Reddy, and Ramesh Vadde. 2015. "Environmental Aspects and Impacts Its Mitigation Measures of Corporate Coal Mining" 11:2. https://doi.org/10.1016/j.proeps.2015.06.002

R. Uma Shaanker, K. N. Ganeshaiah, M. Nageswara Rao, and N. A. Aravind. 2004. Ecological Consequences of Forest Use: From Genes to Ecosystem. A Case Study in the Biligiri Rangaswamy Temple Wildlife Sanctuary, South India.

REMA 2015) Rwanda: State of Environment and Outlook Report 2015. Rwanda Environment Management Authority. Kigali, Rwanda.

REMA. 2009. Rwanda state of environment and outlook report.

Rishi, P. 2007. Joint forest management in India: An attitudinal analysis of stakeholders. *Resources, Conservation, and Recycling*, 51(2): 345-354.

RNRA. 2014. REDD Readiness Preparation Proposal for Rwanda.

RNRA-DFNC. 2015. Projection scenario of sypply/demand of wood biomass in Rwanda from 2015 to 2026. Summary report.

RWFA. 2017. WISDOM Rwanda and Woodfuels value chain analysis. Rwanda Supply Master Plan for fuelwood and charcoal.

S. M. Jua´rez-Orozco, C. Siebe, D. Ferna´ndez y Ferna´ndez. 2017. Causes and Effects of Forest Fires in Tropical Rainforests: A Bibliometric Approach.

Seidu, A. 2008. Technical efficiency of rice farmers in Northern Ghana. Tamale, Ghana: AERC Research Paper.

Shackleton CM, Shackleton SE, Buiten E, Bird N. 2007. The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and Economics*, **9**(5):558-577.

Sumati, V. 2006. Examining the socioeconomic drivers of fuelwood dependence in villages on the Northern boundary of Bandipur National Park. MSc. Thesis

Tafere, A. 2013. Factors affecting Forest User's Participation in Participatory Forest Management; Evidence from Alamata Community Forest, Tigray Ethiopia.

Tiziano Gomiero. 2016. Soil Degradation, Land Scarcity and Food Security: Reviewing a Complex Challenge. Sustainability 2016.

Vedeld P, Angelsen A, Sjaastad E. 2004. Counting on the environment: forest incomes and the rural poor, Paper #98. The World Bank Environment Department, Washington, DC.

Wambua S. 2008. An Economic Analysis of Forest Extraction and Its Link to Community Livelihood: The case of Kakamega rainforest. MSc. Thesis.

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Research Article

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The Impact of Synthetic Auxin on Correlation Between Leaf Carotenoids and Mortality Percentage of Mesquite (*Prosopis juliflora* Swarz) DC.

Eltayeb A. H. Suliman*[1], Sayda O. Elhewairis[1] and Salah E. Elamin[2]
[1]*Department of Botany and Agricultural Biotechnology*
[2]*Department of Crop Protection*
Faculty of Agriculture, University of Khartoum, Sudan
**Corresponding author e-mail: eltayeb71_sha@yahoo.com*
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ABSTRACT
In the Faculty of Agriculture - University of Khartoum – Sudan, experiments were conducted in both winter and rainy seasons to assess the impact of the synthetic auxin 2,4-dichloro phenoxy acetic acid (2,4-D) on the relationship between leaves carotenoid content and the mortality percentage of mesquite trees (*Prosopis juliflora*). Mesquite trees of small, medium, and large sizes were treated with the 2,4-D at four weights 6-, 12-, 18-, and 24-grams' active ingredient, each dissolved in either diesel oil or water. The results indicated that the three sizes treated with different weights of herbicide dissolved in diesel showed a high mortality percentage and fewer leaf carotenoid levels, compared to the same weights of 2,4-D dissolved in water. During the rainy season, the high weight of 2,4-D (24 grams a.i.) dissolved in water resulted in a high mortality percentage and lower carotenoid levels, compared to the other 2,4-D weights dissolved in water. The study concluded that; 2,4-D increased the negative relationship between mesquite mortality percentage and the leaf's carotenoid content.
Keywords: 2,4-D, Herbicide, Diesel, Natural, and Negative relationship.

INTRODUCTION
Carotenoids are pigments found in plants, they are lipid-soluble compounds that include beta-carotene, lutein, and zeaxanthin. Carotenoids are one of the most important members of the tetraterpene family of pigments (Arvayo-Enriquez *et. al*, .2013), Carotenoids are important to plant physiology and regulating plant development (Águila and Rodríguez, 2012). 2,4-D is the first synthetic auxin herbicide (phenoxy acetic acid) used to control dicotyledonous annual and perennial weeds (Gervais *et al*., 2008). There are two types of formulations of 2,4-D: amine salts and esters, high temperature and humidity play essential roles in the uptake and movement of the 2,4-D (Peterson *et al.*, 2016). Low doses of 2,4-D promote plant growth while high doses promote plant overgrowth, (Grossmann, 2010).

During normal metabolic processes, reactive oxygen species (ROS) are produced when electrons are transferred to oxygen O_2, forming superoxide radicals, hydrogen peroxide (H_2O_2), and hydroxyl radicals. Alternatively, ROS can also be generated by reduction of O_2 to form single oxygen $^1O_2$ (Mittler, 2002). In low concentrations, hydrogen peroxide (H_2O_2) plays an important role in regulating gene expression related to stress responses and development (Mittler *et al.*, 2011). ROS has a dual, antagonistic role in cells depending on their concentration, plants have developed a sophisticated mechanism to control ROS levels, involving glutathione, tocopherol, polyphenols, and carotenoids (Sandalio *et al*., 2009).

The cells in plants using carotenoids to neutralize toxic ROS, which act as antioxidants, detoxifying various forms of ROS (Varin and Sekhon, 2006). Carotenoids also act as an antioxidant, scavenging $^1O_2$ to inhibit oxidative damage (Edreva, 2005) and they serve as signaling molecules in response to biotic and abiotic stress (Li and Vallabhaneni, 2008). Additionally, carotenoids protect the plant against UV radiation (Young, 1991), This study aimed to assess the link between the leaf carotenoid content, mesquite mortality percentage, and the role of 2,4-dichloro phenoxy acetic acid.

MATERIALS AND METHODS
Sites of the Experiments and Plant Materials
Field experiments were carried out at the Faculty of Agriculture, University of Khartoum, Sudan. The site is located at lat.15, 40 N, long 32, 32E, in a semi-arid zone, with a wide range of temperatures, varying from 18o C to 40o C, and relative humidity ranging from 34% to 75

% (Gabbani, 2007). The experiment area was divided into three replicates, each containing thirty mesquite trees, that were classified based on their size to three categories small, medium, and large, with ten in each category.

Chemical solutions and application method

The method outlined in (Geesing et al. 2004) was utilized, to apply herbicide to the lower portion of the stem. This involved spraying the 2, 4-D herbicide at four rates (6-, 12-, 18-, and 24-grams a.i), using either diesel or water as a solvent, each weight of 2, 4-D dissolved in a liter of the solvent.

Data Collection

Extraction and estimation of carotenoid

The leaves from the outermost branches of each tree were selected two weeks after herbicide application. The collected leaves were placed in polyethylene bags and stored in a deep freeze at -20º C. The carotenoid content determined following the method described by Porra *et.al*. (1989), 0.05 grams of frozen leaves were ground into fine particles in a mortar using 2 ml of pure methanol per 0.1 gram until the tissues become colorless. The mixture was then centrifuged at 6000 rpm for 15 minutes, following which 0.5 ml of the supernatant was transferred to a new test tube, to this 4.5 ml of pure methanol was added and the absorption was measured using a spectrophotometer at 665, 650, and 470 nm. The amount of carotenoid was then calculated as mg / g green tissue using specific equation:

$$\text{Carotenoid} = \frac{1000 \times A470 - (1.63 \times A665 + 104.9 \times A650) \times V}{221 \times W}$$

A665 = Absorption at wavelength 665 nm.
A650 = Absorption at wavelength 650 nm.
A470 = Absorption at wavelength 470 nm.
V = the final volume of the pure methanol in chlorophyll extract.
W = the fresh weight (gram).

Mortality percentage

The mortality percentage is calculated one year after applying the herbicide to allow sufficient time for the herbicide to take effect in different climatic conditions. The stem appears 100 % defoliated, have no living tissue, and have not re-sprouted from ground buds was accounted. The mortality was calculated as percentage of the total number of stems.

Experimental design and data analysis

The experiments were conducted using Randomize Complete Block Design (RCBD) with three replicates. The data was analyzed using an Analysis of variance (ANOVA) test, and means were separated statistically using the least significant difference (LSD) test with a computer statistical software, "Statistix 10". Differences between means were considered significant at the (0.05) level.

RESULTS AND DISCUSSIONS

The combination of 2,4-D and diesel solvent resulted in a significant decrease in carotenoid content of the leaves and a higher mortality percentage for trees of all sizes compared to the control group. The increase in mortality percentage was linked to a *decrease* in carotenoid content as the 2,4-D application rate increased. Small, medium, and large trees treated with all rates of 2,4-D mixed with diesel showed high mortality percent, while carotenoid levels significantly decreased as the amount of 2,4-D increased. In all trees sizes, there were no significant differences in mortality percentage and leaves carotenoid content for all rates of 2,4-D dissolved in water. However, during the rainy season, the high rate of 2,4-D dissolved in water resulted in a significant increase in mortality percentage and a decrease in leaves carotenoid for medium; and large tree sizes (Tables 1 and 2).

All rates of 2,4-D dissolved in diesel solvent resulted in significantly lower leaf carotenoid content, and increased mortality percentages compared to when it was dissolved in water. In contrast, the rates of 2,4-D dissolved in water showed no significant difference. During the rainy season, the high rate of 2,4-D (24 grams a.i.) dissolved in water significantly reduced leaf carotenoid content, and increased mortality percentage, which gave (2.58 mg) and (28.79%) compared to the control, which gave 0.00 mortality percentages and 3.58 mg, of leaf carotenoid (Table 3).

Synthetic auxins 2,4-D imitate the effects of natural auxin (IAA) in plants (Pazmino *et al.,* 2012). Natural auxins IAA are quickly deactivated as they are conjugated and degraded, while 2,4-D persist in the plant for longer periods (Song, 2014). 2,4-D triggers specific peroxisomal enzymes that lead to the production of reactive oxygen species (ROS). Including analyzed glycolate oxidase (GOX) involved in photorespiration, xanthine oxidoreductase (XOD) involved in ureide metabolism, and acetyl-CoA oxidase (ACX) involved in fatty acid β-oxidation (Pazmino *et al.*, 2011).

Carotenoids are synthesized in chloroplasts and various types of plastids, but their high levels are predominantly found in the chloroplasts (Aguila 2012). Chloroplasts have been identified as the primary target of 2,4-D (Grossmann, 2009), resulting in decreasing levels of chlorophyll and carotenoids (Saygideger, 2008). The increase of ROS produced by 2,4-D may be responsible for the enhanced carotenoid degradation (Grossmann *et al*., 2001).

2,4-D activates the synthesis of 1-amino cyclopropane 1-carboxylic acid (ACC), which is the key enzyme in ethylene biosynthesis (Grossmann, 2003). This process is stimulated by Abscisic acid (ABA) biosynthesis (Raghavan, 2006). ABA accumulation causes stomatal closure, and reduces water loss (Vanderauwera *et al.*, 2011), Stomatal closure limits CO_2 assimilation leading to a reduction in photosynthetic activity and increased electron leakage from the photosystems to O_2 in the chloroplasts (Grossmann, 2010), This induces

overproduction of (ROS) such as superoxide radicals (O•− 2), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH +). which, leading to oxidative damage (Eduardo *et al.*, 2017).

In addition, the high accumulation of ROSs leads to oxidative damage to proteins, polyunsaturated fatty acids, and nucleic acids (Sandalio *et al.*, 2012) Furthermore, H_2O_2 production resulted in tissue damage and cell death (Grossmann, 2010).

Table 1. Effect of 2,4-D rates, solvent types and tree sizes on mortality percent and leaf's carotenoid content in the winter season.

Tree sizes	2,4-D rates (gram a.i.)	Diesel		Water	
		Mortality %	Carotenoid mg	Mortality %	Carotenoid mg
Small	Control	16.67 ef	2.49 i	0.00 f	2.84 ghi
	6	55.33 cde	2.49i	0.00 f	2.99 f g h
	12	83.33 abc	1.70 j k	0.00 f	3.23 c defg
	18	100 a	1.43 kl	0.00 f	3.18 defg
	24	100 a	1.71 j k	0.00 f	3.58 bc
Medium	Control	16.67 f	2.65 hi	0.00 f	3.30 c def
	6	56.67def	1.84j	0.00 f	3.24 c defg
	12	93.33ab	1.64jk	0.00 f	3.29 c def
	18	100 a	1.33kl	0.00 f	3.41 bcd
	24	100 a	1.17 l	0.00 f	3.75 b
Large	Control	13.33f	3.01 e f gh	0.00 f	4.17 b
	6	53.33cde	1.60 j k	0.00 f	2.75 hi
	12	56.67bcd	1.92 j	0.00 f	3.73 b
	18	93.33ab	1.13 l	0.00 f	3.40 b cde
	24	100 a	0.66 m	0.00 f	3.28 c def
SE±		16.14	0.20	16.14	0.20

Table 2. Effect of 2,4-D rates, solvent types and tree sizes on mortality percent and leaf's carotenoid content in the rainy season.

Tree sizes	2,4-D rates (gram a.i.)	Diesel		Water	
		Mortality %	Carotenoid mg	Mortality %	Carotenoid mg
Small	Control	46.67 bc	2.99 def	0.00 f	3.09 de
	6	100 a	2.81 d efg	0.00 f	3.38bcd
	12	100 a	2.61 efghi	0.00 f	2.71 d efgh
	18	93.33a	2.16 ghij	0.00 f	2.96 def
	24	93.33a	1.99 ij	0.00 f	2.34fghij
Medium	Control	48.33b	3.06 de	0.00 f	4.22a
	6	93.33a	3.13 cde	0.00 f	3.40bc
	12	93.33a	2.55 ef g hi	6.67 e f	3.11cde
	18	100 a	2.05 hij	16.67de	2.89def
	24	100 a	1.71 j	33.33cd	2.75defg
Large	Control	50 b	3.37 bcd	0.00 f	3.14 bc de
	6	100 a	2.87 defg	0.00 f	3.84 ab
	12	100 a	2.78 def g	0.00 f	3.81 abc
	18	100 a	1.96 ij	0.00 f	2.94 f
	24	100a	1.73 j	53.33b	2.66 fghi
SE±		7.00	0.35	7.00	0.35

Table 3. Effect of 2,4-D rates on mortality percent and leaf's carotenoid content in the winter and rainy seasons.

2,4-D rate (gram a.i.)	Winter season		Rainy season	
	Mortality %	Carotenoids mg/g	Mortality %	Carotenoids mg/g
Diesel only	15.56 c	2.72 d	47.22 b	3.14 a
Diesel+6 grams	64.44 b	2.25 e	97.78 a	2.93 ab
Diesel+12 grams	67.78 b	1.65 f	97.78 a	2.65 b
Diesel+18 grams	97.87 a	1.46 f	97.78 a	2.06 c
Diesel+24 grams	100 a	1.18 g	97.87 a	1.81 c
Water only	0.0 c	3.29 bc	0.00d	3.58 a
Water+ 6 grams	0.00 c	3.07 c	0.00 d	3.32 a
Water+ 12 grams	0.00 c	3.48 ab	2.22 d	3.29 a
Water+ 18 grams	0.00 c	3.33 ab	5.56 d	3.08 ab
Water+ 24 grams	0.00 c	3.54 a	28.79 c	2.58 b
SE±	9.94	0.12	3.68	0.20

CONCLUSION

The study discovered a negative correlation between the levels of carotenoids in leaves and the percentage of mesquite mortality. The research also confirmed that 2,4-D has a significant impact on strengthening this relationship.

Furthermore, the study showed that 2,4-D dissolved in diesel is more effective than when it dissolved in water. This difference in efficacy is attributed to the distinct properties of the solvents used.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

REFERENCES

Águila, M. R. S. and Rodríguez, M. 2012. Carotenoid biosynthesis in arabidopsis: a colorful Pathway. The Arabidopsis Bool/ *American Society of Plant Biologists.*

Arvayo-Enríquez, H, I Mondaca-Fernández, P Gortárez-Moroyoqui, J López-Cervantes, and R Rodríguez-Ramírez. 2013. "Carotenoids extraction and quantification: a review."*Analytical Methods* **5** (12): 2916–2924.

Edreva, A. 2005. "Generation and scavenging of reactive oxygen species in chloroplasts: a sub-molecular approach." *Agriculture, Ecosystems & Environment* **106** (2–3):119–133.

Gabbani, M. F. 2007. *Amelioration of Biotic Stress Induced by Onion Yellow Dwarf Virus on Onion Seed Crop Using Nutrition*. M.Sc. (Agric) thesis. University of Khartoum, Khartoum, Sudan. p. 25

Geesing, D.; Al-Khawlani, M. and Abba, M. L. 2004. Management of introduced *Prosopis juliflora* species: can economic exploitation control an invasive species Unasylva, **55**(217): 36-44.

Gervais, J. A.; Luukinen, B.; Buhl, K. and Stone, D. 2008. 2,4-D Technical Fact Sheet; National pesticide information Center, Oregon State University Extension Services.

Grossmann, K., Kwiakowski, J. and Tresch, S., 2001. Auxin herbicides induce H_2O_2 overproduction and tissue damage in cleavers (*Galium aparine* L.) *Journal of Experimental Botany* **52**:1811-1816.

Grossmann K 2003. Mediation of herbicide effects by hormone interactions. *J Plant Growth Regular* **22**: 109–122.

Grossmann K. 2010. Auxin herbicides: status of mechanism and mode of action. *Pest management science*. **66**(2): 113 -120.

Li, F. and Vallabhaneni, R. 2008. The Maize Phytoene Synthase Gene Family overlapping roles for carotenogenesis in the endosperm, photomorphogenesis, and thermal stress tolerance. – *Plant Physiol*. **147**: 1334-1346.

Mittler, R.; Vanderauwera, S.; Suzuki, N.; Miller, G. A. D.; Tognetti, V. B.; Vandepoele, K.; Gollery, M.; Shulaev, V. and Van Breusegem, F. 2011. ROS signaling: the new wave. Trends in Plant Science **16**(6): 300–309.

Pazmino, D. M.; Rodríguez-Serrano M.; Romero-Puertas, M. C.; Archilla-Ruiz, A.; Del Río, L. A. and Sandalio, L. M. 2011. Differential response of young and adult leaves to herbicide 2,4-dichloro phenoxy acetic acid in pea plants: role of reactive oxygen species. *Plant Cell Environment* **34**(11): 1874-1889.

Pazmino, D. M.; Romero-Puertas, M. C. and Sandalio, L. M. 2012. Insights into the toxicity mechanism of and cell response to the herbicide 2,4-D in plants. Plant signaling & behavior **7**: 425-427.

Peterson, M. A.; McMaster, S. A.; Riechers, D. A.; Skelton, J. and Stahlman, P. W. (2016).2,4-D past, present, and future: A review. *Weed Technology* **30**(2): 303-345.

Porra, R. J., Thompson, W. A. and Kriedemann, P. E.1989. Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and extracted with four different solvents: verification of the concentration of chlorophyll standards by atomic absorption spectroscopy. *Biochemical and physiological Acta* **975**: 384-394.

Sandalio, L. M.; Rodriguez-Serrano, M.; Gupta, D. K.; Archilla, A.; Romero-Puertas, M. C. and Rio, L. A., 2012. Reactive oxygen species and nitric oxide in plants under cadmium stress: From Toxicity to Signaling in the book: Environmental Adaptations and Stress Tolerance of Plants in the Era of Climate Change. *Bertin*: Springer, pp.199-215.

Saygideger, S. D. and Okkay, O. 2008. Effect of 2,4-dichloro phenoxy acetic acid on growth, protein, and chlorophyll-a content of *Chlorella vulgaris* and *Spirulina platensis* cells. *J Environment Biol.* **29**:175-180.

Song, Y. L. 2014. Insight into the mode of action of 2,4-dichloro phenoxy acetic acid (2,4-D) as an herbicide. *Journal of Integrative Plant Biology* **56**(2): 106-113.

Vanderauwera, S.; Suzuki, N.; Miller, G.; van de Cotte, B.; Morsa, S. and Ravanat, J. L. 2011. Extranuclear protection of chromosomal DNA from oxidative stress. Proceedings of the National Academy of Sciences USA **108**(4): 1711 – 1716.

Varin P. and B. S. Sekhon. 2006. Reactive Oxygen Species and Antioxidants in Plants: An Overview *Journal of Plant Biochemistry and Biotechnology* **15**: 71-78.

Young, J., 1991. The photoprotective role of carotenoids in higher plants. *Physiolgia Plantarum* **83**(4): 702-708.

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